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A proposed low level radioactive waste disposal site

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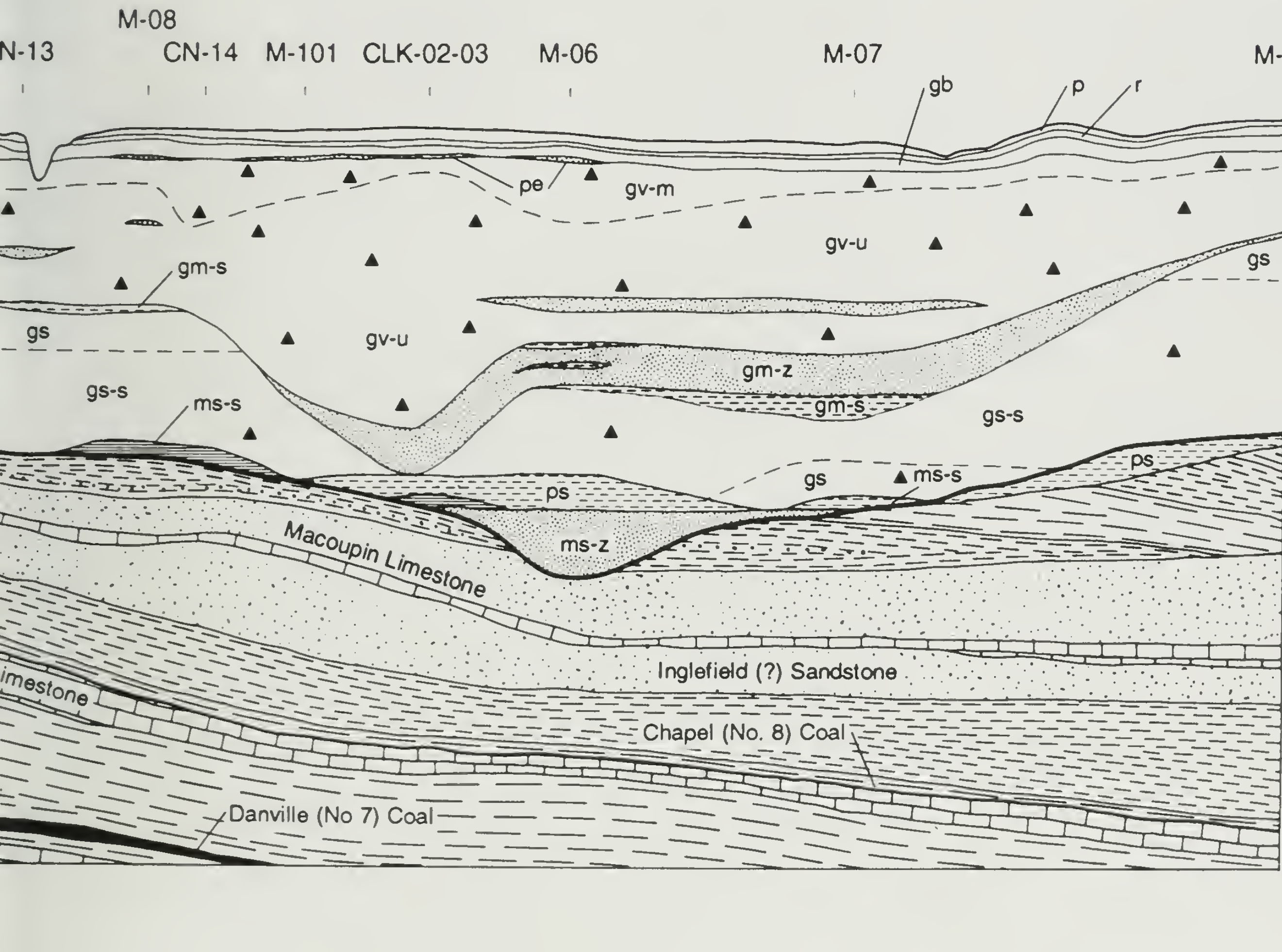

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Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

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A proposed low level radioactive waste disposal site

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Cover Cross section of the Martinsville Alternative Site shows the bedrock and glacial drift units. Length of section is approximately 5,000 feet; vertical exaggeration is 10x.

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ABSTRACT

The Martinsville Alternative Site was intensely studied as part of a characterization program to select a potential site for the disposal of low level radioactive waste in Illinois. As much as 206 feet of Quaternary deposits, mostly composed of glacigenic sediment of Illinoian age, overlie Pennsylvanian bedrock at the Martinsville site. Sedimentation was strongly affected by two buried valleys carved into the bedrock. The thickest known occurrences of four lithostratigraphic units constitute the bedrock valley sediment fill.

Unique features of the lithostratigraphic units are shown in detailed isopach maps, cross sections, and structure contour maps. For example, a cone-shaped feature (apex down) composed of the uppermost till unit (the Vandalia Till Member of the Glasford Formation) disrupts the continuity of several underlying units. Also, the thickest and most continuous sand and gravel units occur at the bottom and top of the sediment sequence that fills the bedrock valleys. The intensely examined stratigraphic succession at this site has strengthened our understanding of the regional glacial stratigraphic framework in central Illinois for use in future geological, engineering, and environmental studies.

EXECUTIVE SUMMARY

The Martinsville Alternative Site (MAS) was proposed by the State of Illinois for a low level radioactive waste disposal facility. Located in east-central Illinois north of the city of Martinsville, the MAS covers 1,380 acres. To characterize the site, geological and hydrological investigations were conducted by the primary contractors, Battelle Memorial Institute and Hanson Engineers, Inc. (1990 a, b, c), and by the Illinois State Geological Survey (Curry et al. 1991a, b) and the Illinois State Water Survey (1990a, b). This report is a synthesis of the geological investigations of the MAS; results of hydrological investigations are discussed only to provide insights to the geometry and continuity of geologic units. Investigations of the MAS constitute the most comprehensive geological study of Quaternary glacial sediments ever conducted in this part of Illinois. The studies helped to delineate the succession of lithostratigraphic units at the MAS and to integrate the stratigraphy and depositional environments of geologic units into the broader regional context. Interpretations of the geologic units at the MAS strengthened our understanding of the glacial stratigraphic framework for use in future geological, engineering, and environmental studies in east-central Illinois.

The Quaternary succession at the MAS includes 20 to 206 feet of Illinoian alluvium and glacigenic deposits. This sediment fills four bedrock valley segments carved into the Pennsylvanian Modesto and Bond Formations. The Quaternary glacigenic sediments are covered by a thin mantle that is less than 14 feet thick and composed of weathered Sangamonian sediment and Wisconsinan loess and alluvium.

Important findings of this study are as follows:

(1) Each Quaternary lithostratigraphic unit at the MAS may be differentiated by some combination of stratigraphic position, particle-size distribution, sorting coefficient, and semiquantitative mineralogy of the <2 μm fraction. The interpretation of stratigraphically complex or hydrogeologically critical zones required evaluation of all characteristics listed above. Other helpful attributes for differentiating units included pedologic features, moisture content, and Atterberg limits.

(2) The thickness and distribution of glacigenic and preglacial Quaternary lithostratigraphic units at the MAS are influenced by the buried bedrock topography. The Martinsville bedrock valley extends beneath the MAS and contains the thickest known occurrences of Petersburg Silt (50.4 ft) and two members of the Glasford Formation, Smithboro Till (90.4 ft) and Vandalia Till (129.4 ft). The North Fork Embarras bedrock valley contains the thickest known occurrence of the Mulberry Grove Member (58 ft) of the Glasford Formation.

(3) The network of Quaternary buried bedrock valleys incised in Pennsylvanian bedrock appears to have been affected by superposition and piracy of valley segments during pre-Illinoian glaciation. Because the buried bedrock valleys appear to have had a southward gradient during the earliest Illinoian, the Petersburg Silt probably was deposited in a slackwater lake in response to aggradation in the ancestral Wabash and lower Embarras Rivers.

(4) The thickest and most continuous Quaternary sand and gravel units occur along the bedrock valleys, especially the sand and gravel facies of the Martinsville sand and Cahokia Alluvium, which were deposited during nonglacial intervals. The Martinsville sand, the lowest aquifer in the glacial drift succession, was deposited in the deepest portion of the bedrock valleys. Along two significant buried bedrock valleys, the sand and gravel facies of the Mulberry Grove Member is also thick and continuous; however, at the MAS, the continuity is disrupted by the overlying Vandalia Till Member. The sand and gravel facies of the Mulberry Grove Member is thickest (as much as 58 ft) along the North Fork Embarras bedrock valley, which generally underlies the present-day North Fork Embarras River valley near Martinsville and the MAS.

(5) The lithologic succession beneath the modern valley of the North Fork Embarras River generally includes two aquifers within 60 feet of the ground surface. The two aquifers are the sand and gravel facies of the Mulberry Grove Member and the Cahokia Alluvium. These units are separated by a thin layer (<15 ft) of diamicton belonging to the Vandalia Till Member.

(6) The Vandalia Till Member of the Glasford Formation is the most widespread and thickest deposit at the MAS. Near the center of the MAS, the Vandalia is as much as 129.4 feet thick where the lower surface of the unit is shaped like an inverted cone. The Vandalia thins to about 55 feet across a radial distance of about 1,000 feet from the inverted apex. The origin of this feature is unknown, although it is likely related to subglacial erosion along a preexisting channel.

INTRODUCTION

In 1988, the Illinois State Geological Survey (ISGS) and Illinois State Water Survey (ISWS) participated in detailed investigations to characterize the geology and hydrology of a proposed area, known as the Martinsville Alternative Site (MAS), for disposal of low level radioactive wastes. The detailed characterization of the site was undertaken to provide knowledge about subsurface conditions and variability of the geologic materials for use in hydrologic flow modeling, design of engineered structures, and overall suitability assessment of the site.

The Illinois Department of Nuclear Safety (IDNS) contracted with Battelle Memorial Institute, Columbus, Ohio, and Hanson Engineers, Inc., Springfield, Illinois, to conduct the site characterization studies. Hanson Engineers, Inc. planned and implemented site characterization activities at the MAS. The technical disciplines emphasized in the characterization were geology, hydrology, and geotechnology. Specific investigations, tests, and analyses included geologic mapping; geological resource evaluation; geotechnical analysis; geophysical surveys; drilling, sampling, and logging of rock and sediment samples; surface elevation and surface water surveys; and flood hazard, landform stability, and seismicity analyses.

Hanson Engineers, Inc., subcontracted Shannon and Wilson, Inc., Seattle, Washington, as the primary investigator for many elements of the technical program, including geologic mapping and analysis of the stratigraphy and lithology, geomorphic stability, and seismicity.

The ISGS and the ISWS were initially contracted by the IDNS and later by Battelle to (1) review the reports prepared by the other contractors for scientific and technical accuracy, (2) advise other contractors on site characterization activities and adequacy of the data, (3) examine and analyze geological and groundwater samples and other data in cooperation with the contractors, and (4) prepare interpretative reports of the site geology, including correlating the site geology to the broader, regional framework.

Knowledge of physical properties, thickness, distribution, genesis, and age of the geologic units was used to develop the site-specific geologic framework needed for groundwater and geochemical modeling of the MAS (Beard et al. 1991). Beyond these purposes, investigations of the MAS also constituted the most comprehensive geological study of Quaternary sediments ever conducted in this part of Illinois. The studies helped to delineate the succession of lithostratigraphic units at the MAS and to integrate the stratigraphy and depositional environments of geologic units into the broader regional context. Interpretations of the geologic units at the MAS have strengthened our understanding of the regional glacial stratigraphic framework for use in future geological, engineering, and environmental studies in east-central Illinois.

This report is a synthesis of the geological investigations of the MAS. Results of hydrological investigations are discussed only to provide insights into the geometry and continuity of geologic units. Most figures in this report are derived from ISGS contract reports (Curry et al. 1991a, b); figures derived from the contractors' report (Battelle Memorial Institute and Hanson Engineers, Inc. 1990a) to the IDNS are duly noted. Other information about the geology of the MAS was presented in Troost and Curry (1991) and Curry and Troost (1991).

After completion of the various studies, and as this report was being prepared, a special commission appointed by the governor of Illinois concluded that the site was unsuitable for the safe disposal of low level radioactive waste (Simon et al. 1992).

Data Sources

Three primary data sources were used to characterize the regional and site geology of the Martinsville Alternative Site. Data are from

(1) five reconnaissance borings (CLK–01–02 and CLK–03–01 in fig. 1 and CLK–02–01, CLK–02–02, and CLK–02–03 in fig. 2), which provided split-spoon samples about 1.5 feet long. Collected at 5.0 foot intervals (Battelle Memorial Institute and Hanson Engineers, Inc. 1988), these samples were analyzed first to develop the stratigraphic framework.

(2) 103 continuously sampled borings and ten unsampled borings, which provided rock and drift samples, lithologic and geophysical logs, and other data. The borings were drilled at 80 locations, most of which are shown in figure 2. Characterization data from 53 of the borings were used in this study.

(3) 13 outcrops, including three previously described by MacClintock (1929), and four outcrops and one core previously described by Kettles (1980, Curry et al. 1991a).

This database is not identical to that presented in Battelle Memorial Institute and Hanson Engineers, Inc. (1990a, c). Excluded from this database were data from some borings drilled during late stages of site characterization, and from borings that duplicate data of adjacent borings. Data from beyond Battelle's study area, as shown in figure 1, were included. Additional borings were completed at the site as part of the geotechnical design; however, data from these borings

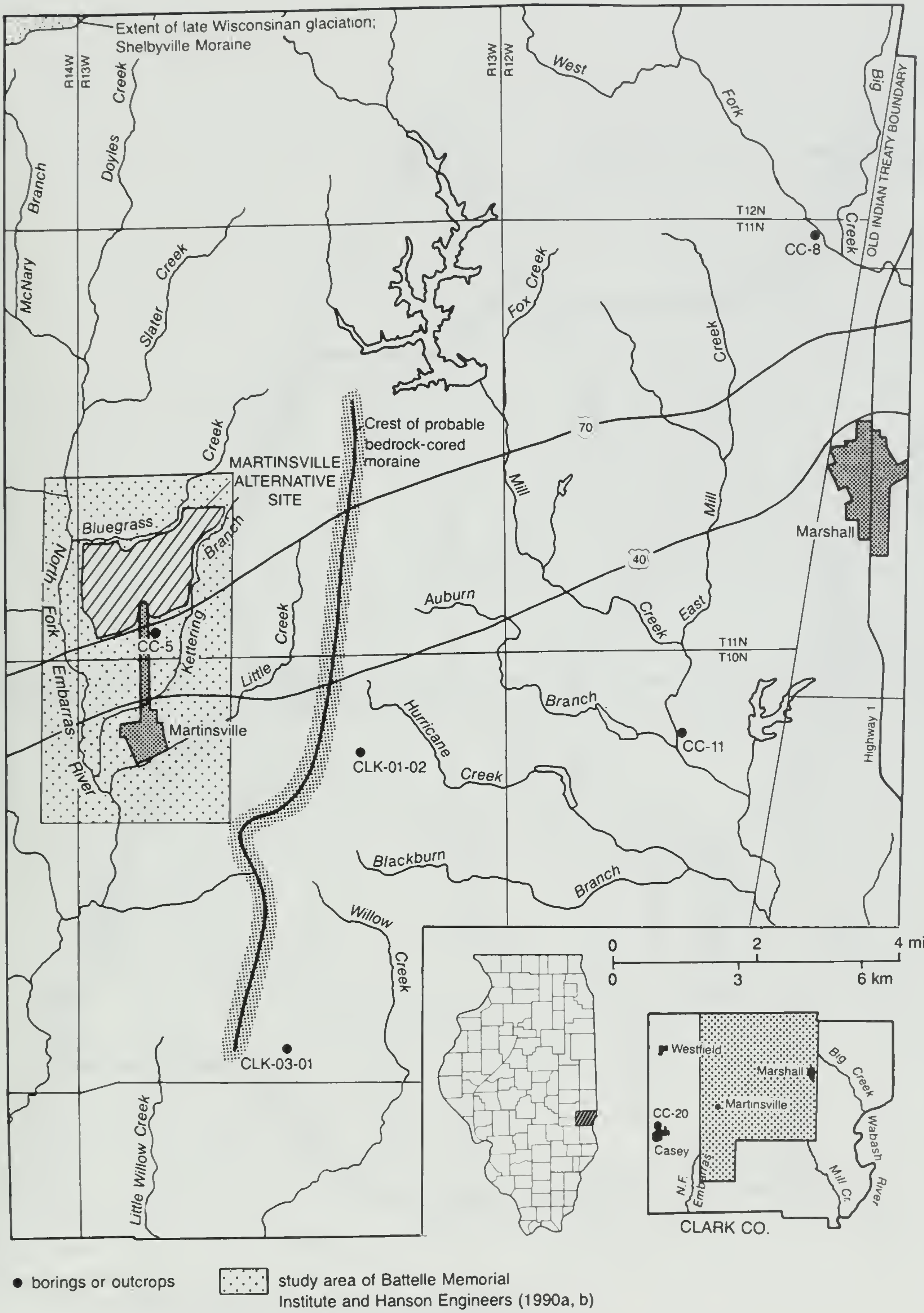


Figure 1 Location of study area, outcrops, and reconnaissance borings.

A
A′
B
B′
C
C′
E
F
G
M-03
M-02
M-07
M-108
M-106
M-102
M-104
M-11
M-125
M-05
M-06
CLK-02-02
CLK-02-03
M-112
M-15
CC-15
CC-16
CC-17
CC-19
M-121
M-122
M-123
M-14
M-131
CN-15
M-101
CN-02
CN-01, M-135
M-10
M-109
M-105
M-08
CN-14
M-103
CN-13
M-130
CN-10
CLK-02-01, M-09
M-01
M-119
M-04
M-129
M-124
M-107
M-110
M-127
M-120
M-13
CC-18
M-128
M-12
M-111
M-126
Kettering
Branch
Bluegrass
Creek
North Fork Embarras River
alternative site boundary
70
630
600
R14W
R13W
T 11 N
T 10 N
25
28
29
30
31
32
36
5
6

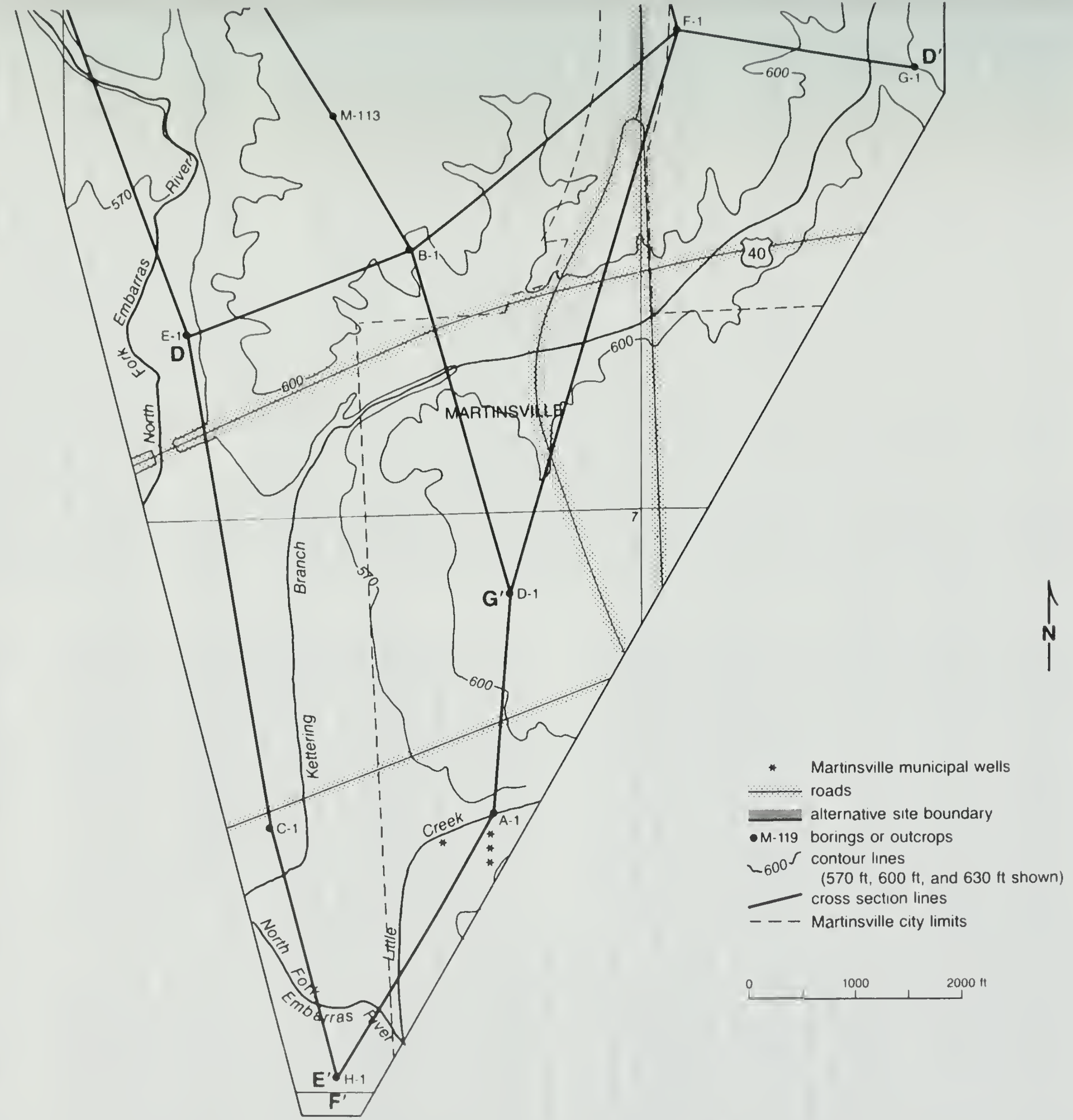


Figure 2 Generalized topography, location of outcrops, test holes, and section lines at the Martinsville Alternative Site (MAS). Lines of section for figure 3 and figures 11 to 16 also are shown.

were not incorporated into this report because of time constraints.

Quality Assurance

The quality assurance guidelines of the Battelle Memorial Institute (Hanson Engineers, Inc. 1989a, b) were followed in gathering and preparing new data from all borings except reconnaissance borings (CLK series). Technical procedures used in this study included those for core and outcrop descriptions, semiquantitative mineralogical analysis of the <2 µm fraction of subsamples of core, radiocarbon dating, and particle-size analyses by hydrometer and wet sieving (ISGS 1989). Hanson Engineers, Inc. generated other data, also summarized in this report. These data include core and outcrop descriptions, moisture content, particle-size determinations by hydrometer and wet sieving, coefficient of uniformity, Atterberg limits (plastic limit, liquid limit, and plasticity index), and petrographic analysis of the fine grained sand fraction. Data in the project technical database (Battelle Memorial Institute and Hanson Engineers, Inc. 1990c) were collected and prepared in accordance with Battelle's quality assurance program (Hanson Engineers, Inc. 1989a, b). Dr. William McCoy, University of Massachusetts at Amherst, provided 11 amino-acid racemization measurements of gastropod shells to aid in regional stratigraphic correlations. The amino acid analyses also were not conducted under the quality assurance plan. Data from all three sources are listed in Battelle Memorial Institute and Hanson Engineers, Inc. (1990c) and in Curry et al. (1991a, b).

Laboratory Methods

Particle-size distribution The percentage of gravel (>2 mm) was calculated from the subsample. The weight of the gravel fraction was removed when calculating the relative percentages of sand, silt, and clay in the <2 mm fraction of subsamples. The categories of particle-grain size of the <2mm fraction included sand, 2 mm to 0.063 mm; silt, 0.063 mm to 0.004 mm; and clay, <0.004 mm. Hanson Engineers, Inc. determined most of the particle-size distributions by sieve and hydrometer analyses. The ISGS extrapolated particle-size data from Hanson's grain-size curves, which were based on sieve and hydrometer analyses, and determined additional grain sizes by using a hydrometer or a SediGraph, which is an automated X-ray absorption technique. The SediGraph analysis provides a cumulative plot of grain-size percentages for all particles <53 µm; distributions of coarser particle sizes were determined by wet sieving. Class nomenclature for grain size, such as loam and silt loam, follows that of the U.S. Department of Agriculture (Buol et al. 1980).

Clay mineralogy The <2 µm (<.002mm) fractions of approximately 1,500 samples from outcrops and cores were semiquantitatively analyzed for clay mineralogy. The procedure used is discussed in ISGS (1989). Other selected clay mineral analyses, reported by Kettles (1980) and listed in the appendix, were performed by Dr. Herbert D. Glass, ISGS, who developed the technical procedure discussed in ISGS (1989), Hallberg et al. (1978), and Wickham et al. (1988).

Sand petrography The lithologies of fine grained sand particles from subsamples of various sand units were determined by point counting. The samples were prepared in a thin-section laboratory (Thresher and Son, Inc., Madison, Wisconsin) that met Battelle's quality assurance guidelines. A split of each sample was washed on a 38 µm sieve to remove silt and clay-sized particles. Each sample was dried and placed into a mold and mixed with epoxy. The resulting solid tab was polished, mounted to a glass slide, and ground to a standard thickness. During analyses under a petrographic microscope, a 1 mm square grid was optically overlain on the prepared slide. The lithology was identified for 300 grains that lay on or nearest to nodes on the grid. Point counts were made on the basis of 12 categories of lithic fragments; general slide quality, grain size, and sorting were also noted.

Interpretation of Laboratory Data

Geologic units (table 1) were characterized and differentiated by visual description and stratigraphic position, augmented by data from semiquantitative clay mineralogical analyses, particle-size distribution, and the coefficient of uniformity (appendix). Less useful were data related to sample moisture, such as moisture content and Atterberg limits. Nondiagnostic data, which include the coefficient of curvature, liquidity index, specific gravity, and porosity, are not listed in the appendix of this report, but they are reported in Battelle Memorial Institute and Hanson Engineers, Inc. (1990c).

The coefficient of uniformity described in the Unified Soil Classification System (Hanson Engineers, Inc. 1989b) was useful in distinguishing till members in stratigraphically complex areas at the MAS. The coefficient is calculated from

$$Cu = D_{60}/D_{10}$$

where Cu = coefficient of uniformity,
D_{60} and D_{10} = the nominal particle-size at the 60th and 10th percent values on a cumulative curve of coarse to fine particles.

The coefficient of uniformity is a relative measure of sorting and takes into account the distribution of fragments that have diameters less than the inside diameter of the sampler. The inside diameter is about 1.8 inches for a split-spoon sampler and about 2.5 inches for a CME continuous sampler. The larger the coefficient, the more poorly sorted (or well graded) the grain-size distribution of the sample.

Table 1 Quaternary lithostratigraphic units of north-central Clark County and the MAS.

Unit (symbol)	Age	Pedostratigraphic unit*	Description (thickness, ft); color of fresh core or outcrop (Munsell notation); plasticity, moist consistence***	Discontinuities
Lacon Formation (l)	Holocene	Modern	Loam diamicton, silt loam (variable); grayish brown (10YR 5/2), yellowish brown (10YR 5/4); plastic to slightly plastic, friable	Pedogenic; roots, burrows, peds, etc.
Peyton Colluvium (pey)	Wisconsinan, Holocene	Modern	Silt loam, loam diamicton (variable); grayish brown (10YR 5/2), brownish yellow (10YR 6/6); slightly plastic, friable	Pedogenic
Cahokia Alluvium (c)	Holocene, Wisconsinan	Modern	Interbedded gravel, fine to medium sand and silt loam (0-35); grayish brown (2.5Y 5/2), gray (N 4/0), yellowish brown (10YR 5/4), dark gray (10YR 4/2); plastic to nonplastic, loose to friable	Lithologic, pedogenic
Parkland Sand (pks)	Wisconsinan	Modern	Fine grained sand (0-7), clean to clayey; very pale brown (10YR 7/3), light gray (N 6/0); slightly plastic, very friable	Pedogenic
Peoria Loess (p)	Wisconsinan	Modern	Silty clay, silty loam (0-7); light brownish gray (10YR 6/2), very pale brown (10YR 7/3), dark grayish brown (10YR 4/2), light gray (2.5Y 7/2), black (10YR 2/1); plastic, friable to firm	Pedogenic
Roxana Silt (r)	Wisconsinan	Farmdale	Loam (1-4); light pinkish gray (7.5YR 6/1), yellowish brown (10YR 5/8), black (N 2/0); plastic, firm	Pedogenic, including krotovina, large Mn nodules and concretions
Pearl Formation (pe)	late Illinoian	Sangamon	Gravelly sandy, clean to clayey, fine grained sand, silty clay (0-13); as above and strong brown (7.5YR 4/6); nonplastic to plastic, loose to firm	Lithologic
Berry Clay Member (peb)	late Illinoian, Sangamonian, Wisconsinan	Sangamon	Silty clay loam, clay loam, loam diamicton (0-12); dark gray (2.5Y 4/1), gray (N 6/0), pinkish gray (7.5YR 6/2), grayish brown (10YR 5/2), black (N 2/0); plastic, firm	Pedogenic, including krotovina, large Mn nodules and concretions
Glasford Formation	Illinoian, late Illinoian, Sangamonian			
Berry Clay Member (gb)	As above	Sangamon	As above	Pedogenic as above
Vandalia Till Member mélange facies	Illinoian			
B-horizon of Sangamon Soil (gv-mx)		Sangamon	As above, (0-2); grayish brown (10YR 5/2), brownish yellow (10YR 6/6), red (2.5YR 4/8), black (5YR 2.5/1); plastic, firm	Pedogenic; subangular blocky structure
C3-horizon of Sangamon Soil (gv-mo)		Sangamon	As above; calcareous except along discontinuities (0-10); light yellowish brown (2.5Y 6/2), brown (10YR 5/3); slightly plastic, firm to extremely firm	As above, but coarser structure
unoxidized diamicton (gv-m)			Chiefly loam diamicton with lenses of gravelly sand, sand and silt (0-34); gray (N 5/0); slightly plastic, firm to extremely firm	Lithologic, sand-filled joints, healed fractures, and glacigenic faults
uniform diamicton facies (gv-u)			Loam diamicton, few sand and gravel lenses (0-129); gray (N 5/0); slightly plastic, extremely firm	Lithologic discontinuities as above, but less frequent
Mulberry Grove Member	Illinoian	Pike		
sand and gravel facies (gm-z)			Sandy loam to sorted sand and gravel (0-31); gray (N 5/0), olive gray (5Y 5/2); nonplastic, loose	Lithologic
diamicton facies (gm-d)			Loam diamicton (<10); gray (N 5/0), greenish gray (5GY 5/1; rare); slightly plastic, extremely firm	Lithologic
silt loam facies (gm-s)			Silt loam, silt (0-10); olive gray (5Y 5/2), gray (N 5/0), dark grayish brown (2.5Y 4/2); slightly plastic to plastic, firm	Lithologic

Table 1 continued

Unit (symbol)	Age	Pedostratigraphic unit*	Description (thickness, ft); color of fresh core or outcrop (Munsell notation); plasticity, moist consistence***	Discontinuities
Smithboro Till Member loam diamicton facies (gs)	Illinoian	Pike (rare)	Loam diamicton (0-44); gray (N 5/0); slightly plastic, firm	Healed fractures, sand-filled joints, infrequent vertical pedogenic cracks
silt loam diamicton facies (gs-s)			Silt loam diamicton (0-58); gray (N 5/0; 5Y 4/1), very dark gray (10YR 3/1), dark grayish brown (2.5YR 4/2), dark olive gray (5Y 3/2), pale olive (5Y 6/3); slightly plastic to plastic, firm to extremely firm	Horizontal shear planes separating lithologic discontinuities
Petersburg Silt (ps)	Illinoian	**	Silt loam, silt, fine- to coarse-grained sand (0-50); pale olive (5Y 6/3), dark olive gray (5Y 3/2), black (5Y 2.5/1); nonplastic to slightly plastic, firm	Lithologic
Martinsville sand	early Illinoian			
silty clay facies (ms-s)		**	Silty clay, clay loam (0-4); greenish gray (5GY 6/1), dark greenish gray (7.5GY 4/1), dark grayish yellow (5Y 4/3), red (10YR 4/6), black (N 2/0); plastic, firm to extremely firm	Lithologic
sand and gravel facies (ms-z)		**	Sand and gravel (0-25); olive gray (5Y 5/2), grayish brown (2.5Y 5/2); nonplastic, loose	Lithologic
diamicton facies (ms-d)			Sandy loam diamicton (0-9); olive gray (5Y 4/2); plastic, firm	Lithologic
Banner Formation				
Lierle Clay Member (bl)	Yarmouthian	Yarmouth	Silty clay, silty clay loam (0-8); gray (N 5/0), olive gray (5/Y 5/2), brown (10YR 5/3); plastic, firm	Lithologic and pedogenic
Casey till member	pre-Illinoian			
B-horizon of Yarmouth Soil (bc-x)		Yarmouth	As above, but leached and with pedogenic features (0-5); grayish brown (10YR 5/2), yellowish brown (10YR 5/6); plastic, firm	Pedogenic; subangular blocky structure
C3-horizon of Yarmouth Soil (bc-o)		Yarmouth	Loam diamicton (0-5); light yellowish brown (10YR 6/4); slightly plastic, extremely firm	As above, but coarser structure
unoxidized diamicton (bc)			Loam, clay loam diamicton (0-30); gray (N 4.5/0, 5Y 4.5/1); slightly plastic, extremely firm	Lithologic, including sand-filled joints, healed fractures
Bond Formation (Pb) and Modesto Formation (Pm)	Pennsylvanian	Yarmouth	Sandstone, shale, siltstone, claystone, mudstone, limestone, coal, conglomerate; variable; variable	Lithologic, joints

*generally, but not necessarily associated with lithostratigraphic unit
**associated with no soil stratigraphic unit, but possesses leached, organic-rich horizons and fragments of wood
***notation from Buol et al. 1980

BEDROCK LITHOLOGY AND STRUCTURE

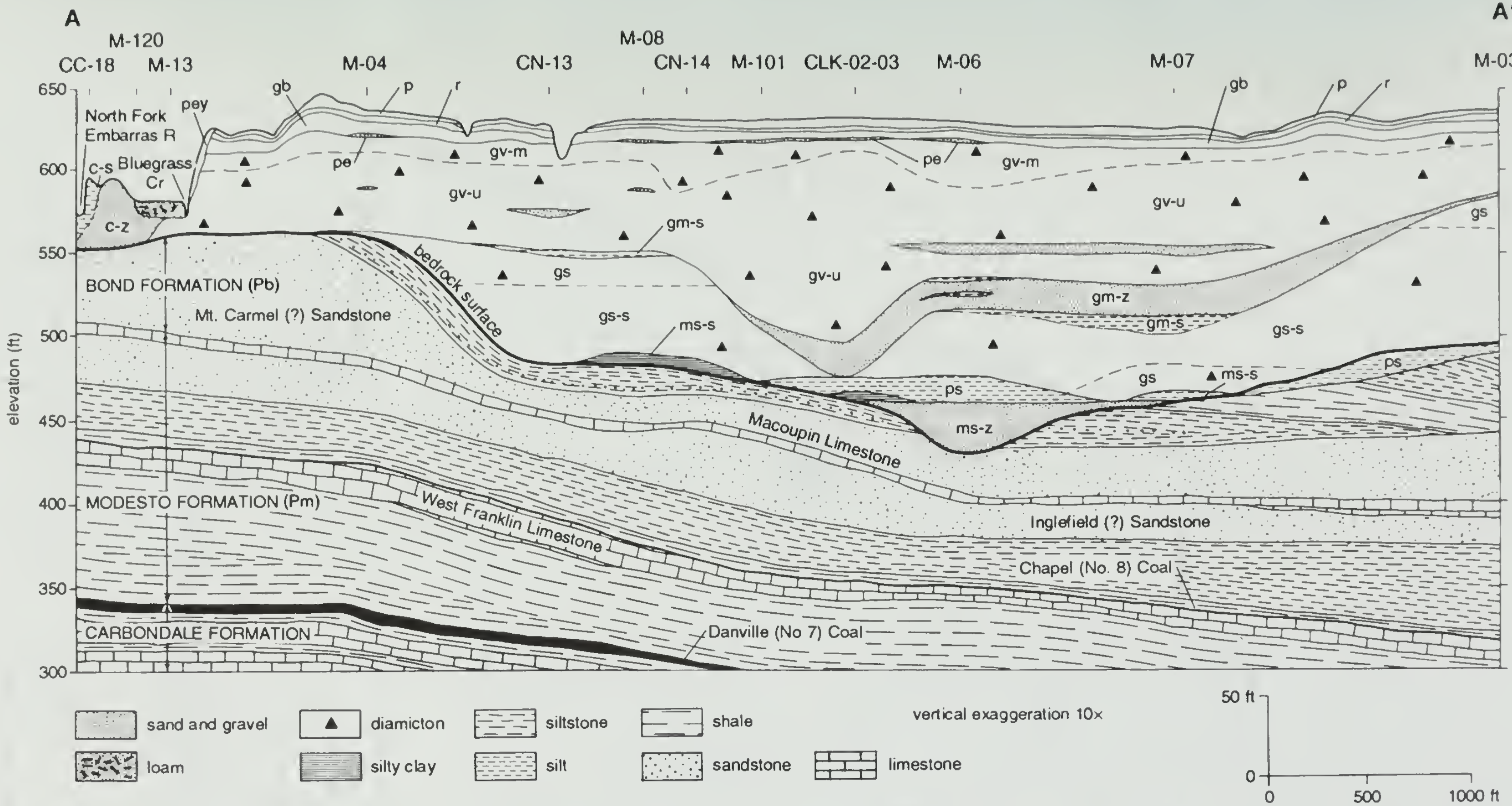
The bedrock that immediately underlies the MAS is composed of Pennsylvanian cyclothemic strata. Pennsylvanian rocks in Illinois are divided into three groups: the McCormick, Kewanee, and McLeansboro Groups, which are subdivided into seven formations (Willman et al. 1975). Three of these formations were encountered in boreholes at the MAS. From base to top, the units include the Carbondale Formation of the Kewanee Group and the Modesto and Bond Formations of the McLeansboro Group (fig. 3).

Carbondale Formation

The Carbondale Formation, about 200 feet thick near the MAS (Willman et al. 1975), is characterized in the Illinois basin by minable coal beds. The uppermost member of the Carbondale Formation, the Danville (No. 7) Coal, is approximately 3.8 feet thick in borings M–03 and M–04. This unit is a regionally significant marker bed. The structure of its upper surface is depicted in figure 4. The underclay associated with the Danville (No. 7) Coal is about 7.5 feet thick at the MAS (Battelle Memorial Institute and Hanson Engineers, Inc. 1990a).

Modesto Formation

The Modesto Formation generally is composed of a series of partial cyclothemic sequences dominated by gray shale and less sandstone, claystone, siltstone, limestone,



	Cahokia Alluvium		Glasford Formation	ps	Petersburg Silt
c-z	sand and gravel facies	gb	Berry Clay Member		Martinsville sand
c-s	silt loam facies		Vandalia Till Member	ms-d	diamicton facies
pey	Peyton Colluvium	gv-m	mélange facies	ms-z	sand and gravel facies
p	Peoria Loess	gv-u	uniform diamicton facies	ms-s	silty clay facies
pks	Parkland Sand		Mulberry Grove Member		Banner Formation
r	Roxana Silt, sandy silt facies	gm-d	diamicton facies	bl	Lierle Clay Member
pe (peb)	Pearl Formation (Berry Clay Member)	gm-z	sand and gravel facies	bc	Casey till member
		gm-s	silt facies	Pb	Bond Formation
			Smithboro Till Member	Pm	Modesto Formation
		gs	loam diamicton facies		
		gs-s	silt loam diamicton facies		

Figure 3 Cross section A–A′. Line of section shown in figure 2. All borings extend into bedrock.

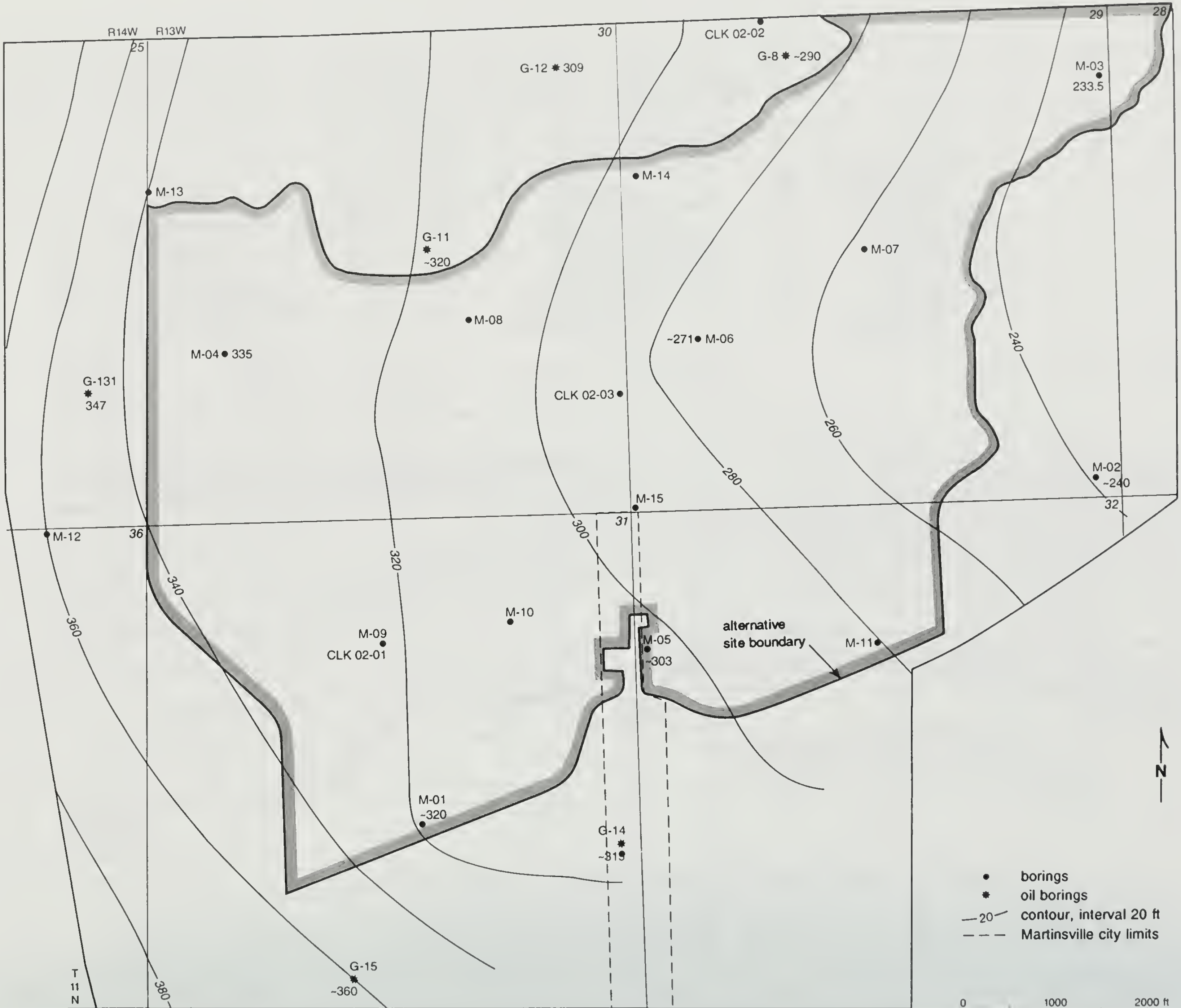


Figure 4 Structure contour map of the upper surface of the Danville No. 7 Coal bed.

and coal. Regionally, the Modesto Formation is about 200 feet thick, but at the MAS, its maximum thickness is 165 feet. The thickness of monolithologic beds within the cyclothemic sequences varies from 1 inch to 60 feet. Shale sequences, including claystone, siltstone, and minor mudstone, are typically about 20 feet thick, but they range from 1 to 50 feet thick. Beneath the MAS, beds of black, carbonaceous, fissile shale range from about 1 to 5 feet thick. Sandstone layers, 6 to 60 feet thick, occur as sheet and channel deposits.

Members of the Modesto Formation at the MAS include, from base to top, the West Franklin Limestone, Chapel (No. 8) Coal, Inglefield Sandstone, Womac Coal, and Macoupin Limestone (?). The West Franklin is composed of light gray, nodular limestone about 6 feet thick. It is overlain by the Chapel (No. 8) Coal, which is composed of an underclay 2.5 feet thick and a fissile coal 0.2 feet thick. The West Franklin Limestone and Chapel (No. 8) Coal are marker beds within the Modesto Formation at the MAS.

Sandstone bodies in the Modesto Formation and the overlying Bond Formation are commonly discontinuous and vary significantly in thickness. These units appear to have been deposited as widespread sheets and channel sands. The channel sands range from 6 to 60 feet thick within a lateral distance of about 8,000 feet. Sheet sands average 20 feet thick. Sandstones commonly are interbedded with siltstones and claystones, and contain sedimentary features such as soft-sediment deformation, crossbedding, and rip-up clasts. Basal intraformational conglomerates containing clasts of coal, limestone, and shale occur locally in the sandstones.

A limestone or calcareous sandstone occurs at the top of the Inglefield Sandstone. Where present, this layer marks the top of the Modesto Formation at the MAS. The layer probably correlates with the Macoupin Limestone of the Modesto Formation, or less likely with the Carthage Limestone (Shoal Creek Limestone) of the overlying Bond Formation (Jacobson 1985).

Bond Formation

The bedrock unit most commonly present at the bedrock surface of the MAS is the Bond Formation. Regionally, the Bond Formation is characterized by about 300 feet of claystone, shale, limestone, and sandstone (Willman et al. 1975). Formal members of the Bond Formation in eastern Illinois include, from base to top, the Carthage Limestone, Mt. Carmel Sandstone, Flannigan Coal, Reel Limestone, and Livingston/Millersville Limestone. At the MAS, the Bond Formation is the uppermost Paleozoic unit. It is overlain unconformably by Quaternary glacial deposits. The Bond Formation is thickest, about 165 feet, on the east side of the MAS. It is absent on the west side and along the walls and floors of several bedrock valley segments beneath the MAS. The upper and lower limestone members of the Bond Formation are not present at the MAS; the Carthage Limestone appears to have been truncated by the Mt. Carmel Sandstone. Identification of the Mt. Carmel is tenuous, however, because of the lack of a distinctive lithology or succession of lithologies separating the Mt. Carmel from the Inglefield Sandstone of the Modesto Formation (fig. 3).

At the MAS, sandstone is the most common lithology at the bedrock surface. The bedrock immediately underlying the glacial deposit is commonly gleyed and breaks easily along bedding planes in the uppermost 3 feet. The sandstone is generally partially cemented with carbonate and contains abundant chlorite; therefore, the friable character is probably diagenetic and not pedogenic.

Bedrock Structure

The MAS is located on the east flank of the Oakland Anticline, a subsidiary fold of the La Salle Anticlinal Belt (Treworgy 1981). The structure contour map of the Danville (No. 7) Coal indicates that the associated strata dip about 0.5° east or 50 feet per mile in the study area (fig. 4). The direction and degree of flexure are consistent with the regional structure (Battelle Memorial Institute and Hanson Engineers, Inc. 1990a). Minor flexures are present in the MAS area (fig. 4). Faults were neither noted nor interpreted from any of the cores recovered at the MAS.

BEDROCK TOPOGRAPHY AND DRIFT THICKNESS

Horberg (1950) mapped the topography of the bedrock surface in Illinois, and Piskin and Bergstrom (1975) mapped drift thickness. At the time of their mapping, however, the number of reliable data points was limited in Clark County. Horberg showed a deep, buried bedrock valley adjacent to the MAS (fig. 5) that nearly coincides with the present-day North Fork Embarras River valley. The buried bedrock valley, which begins northwest of the MAS, is a tributary of a larger buried valley system that extends south and east. Test drilling for characterizing the MAS revealed, in addition to Horberg's original valley, other deep bedrock valley segments beneath and near the MAS. Figure 6 shows the current interpretation of the regional bedrock topography.

Thin drift (glacial and postglacial deposits and related materials) covers a bedrock-cored moraine east of the MAS (fig. 1), as interpreted from surface topography, distribution of bedrock outcrops (Horberg 1950, Kettles 1980), and reconnaissance borings for this study. This moraine locally coincides with the eastern limit of the bedrock valley system that underlies the MAS; older drift units occur east of the moraine (Curry et al. 1989).

The buried valley segments are informally named the North Fork Embarras bedrock valley, and the western, northern, and southern segments of the Martins-

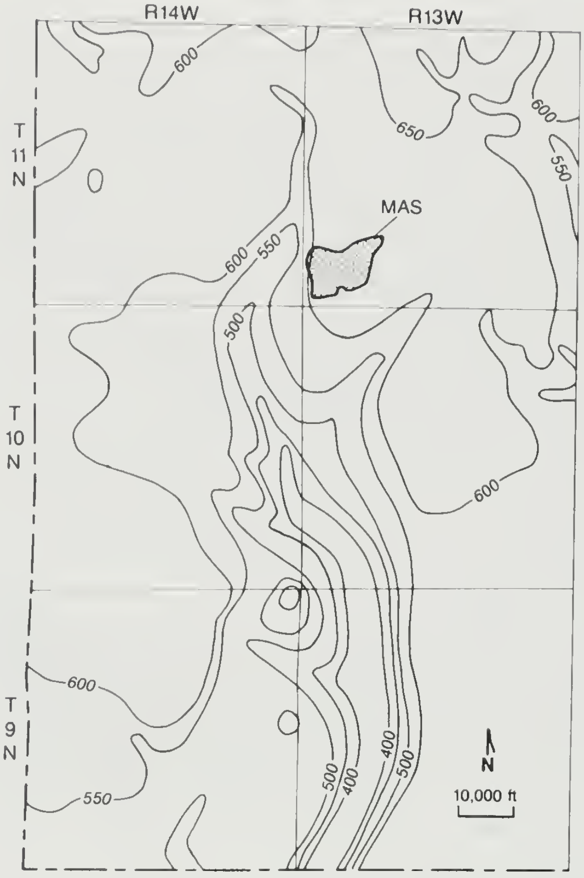


Figure 5 Bedrock topography of part of Clark County as mapped by Horberg (1950).

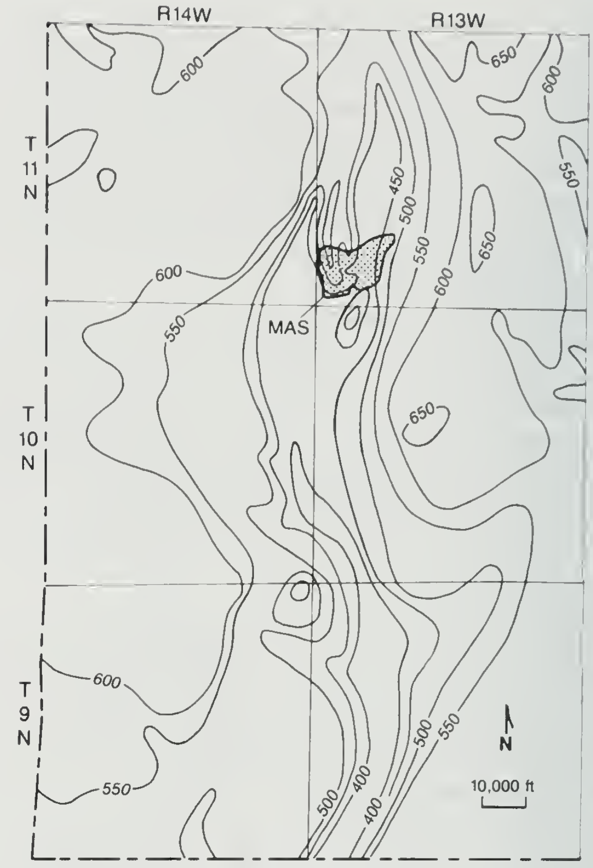


Figure 6 Reinterpretation of bedrock topography shown in figure 5 based on test drilling for the MAS and reconnaissance borings.

ville bedrock valley (fig. 7). The North Fork Embarras bedrock valley is generally parallel and nearly coincident with the modern valley of the North Fork Embarras River as mapped by Horberg (1950). The western and southern segments of the Martinsville buried bedrock valley join the North Fork Embarras bedrock valley southwest of the MAS and in the northern part of Martinsville, respectively (fig. 7). A persistent basal alluvium containing clasts of extraregional lithologies (Martinsville sand) occurs in all segments of the Martinsville bedrock valley. This observation suggests that the segments are connected.

The drainage network of the buried bedrock valleys may be part of an anastomosing pattern (fig. 7). Anastomosing or interconnecting valleys were mapped in large bedrock valleys filled with glacial drift, such as the Teays–Mahomet bedrock valley system (Kempton et al. 1991), in smaller bedrock valley segments in Illinois (Vaiden and Curry 1990), and elsewhere. Anastomosing patterns are relatively common surficial features along valleys that received discharge from glacial meltwater or glacial lake outbursts, such as along the Mississippi, Illinois, and Wabash River valleys (Schumm and Brakenridge 1987). Such patterns result from blockages (local damming), superposed stream segments, and stream piracy.

The bedrock valley network at the MAS was developed during the pre-Illinoian. Although absent from the MAS, pre-Illinoian glacigenic diamicton and sorted sediments are distributed south, west, and east of the study area (MacClintock 1929, Ford 1970, Johnson, Gross, Moran 1971, Johnson et al. 1972, Kettles 1980; Curry et al. 1989, 1991a, b), indicating that the area had been covered by pre-Illinoian ice. Subsequent Illinoian glaciation further eroded bedrock on the valley flanks and divides.

The thickest drift in the study area was measured in boring M–106 (206 ft) in the northeast part of the MAS, above the northern segment of the Martinsville bedrock valley. The thinnest drift (20 ft thick) was noted in boring M–120 immediately northwest of the MAS in the valley of Bluegrass Creek (fig. 8). Bedrock was cored in 49 of the borings evaluated in this study. In 30 of these, 5 feet or more of bedrock was penetrated and sampled. The oldest Quaternary deposits of alluvium and colluvium are derived mostly from the local bedrock, making determination of the bedrock surface difficult in a few places. For the most part, however, contacts between till units and bedrock are sharp, and apparently erosional.

LITHOSTRATIGRAPHY AND PEDOSTRATIGRAPHY OF QUATERNARY DEPOSITS

Physical characteristics, thickness, and distribution of the Quaternary lithostratigraphic units are described in this section. Pedostratigraphic units as they generally occur within the lithostratigraphic framework are described to maintain the overall continuity of this section. Table 1 provides summary descriptions of the stratigraphic units and derivative facies found in north-central Clark County.

Previous Work

MacClintock (1929) described several sections east of the study area along Big Creek and Mill Creek (fig. 1). Although changes have occurred in stratigraphic nomenclature (Jacobs and Lineback 1969, Willman and Frye 1970), his descriptions and interpretations remain valid. He found a thick, pre-Illinoian paleosol (the Yarmouth Soil) developed in wood-bearing till, which was referred to as the Casey till member of the Banner Formation by Ford (1970). MacClintock noted that the top of the paleosol was commonly covered by a thin, fossiliferous, silty unit (Petersburg Silt or the Smithboro Till Member of the Glasford Formation), which in turn is overlain by the uppermost Illinoian unit of the area, a loam till (Vandalia Till Member of the Glasford Formation). The Sangamon Soil is developed in the upper part of the Illinoian deposits. Wisconsinan loess covers the Illinoian deposits in nearly all places, with the exception of stream valleys.

As more of the central Illinois region was explored, the geologic units were described and given informal names (e.g., Jacobs and Lineback 1969, Ford 1970). Willman and Frye (1970) formalized the names and designated type sections; Johnson et al. (1972) and Follmer et al. (1979) summarized regional relationships. Unpublished theses provide additional stratigraphic and clay mineralogical information on Illinoian and pre-Illinoian deposits in central Illinois (Kettles 1980, Hartline 1981, Fox 1987) and Holocene deposits elsewhere in the state (Stanke 1988, Hajic 1990). These studies set the regional framework for recognition of stratigraphic units at the MAS. Recent reports by Battelle Memorial Institute and Hanson Engineers, Inc. (1988, 1990a, b) describe the geology of the MAS, independently of this report. Battelle Memorial Institute and Hanson Engineers, Inc. (1990a, b, c) give informal, site-specific, stratigraphic names to several units. Their terminology is compared with that of this report in table 2.

Banner Formation

The Banner Formation, the oldest known Quaternary lithostratigraphic unit in Clark County, is less than 2 feet thick at the MAS, but it is more than 30 feet thick elsewhere in the study area (fig. 1). As defined by Willman and Frye (1970), the Banner Formation overlies the Afton Soil and underlies either Petersburg Silt or the Glasford Formation. The stratigraphic position of the Afton Soil at its type locality in Afton Junction, Iowa, however, is controversial. The age of pre-Yarmouthian deposits, once called Nebraskan, Aftonian, and Kansan, is now regarded in Iowa as pre-Illinoian (Hallberg et al. 1980), an informal convention that was also adopted in Illinois (Johnson 1986). The informal unit known as the Casey till member of the Banner Formation (described below) contains abundant wood fragments, indicating that an earlier soil once covered the area. Yarmouth Soil is developed in the upper part of the Banner.

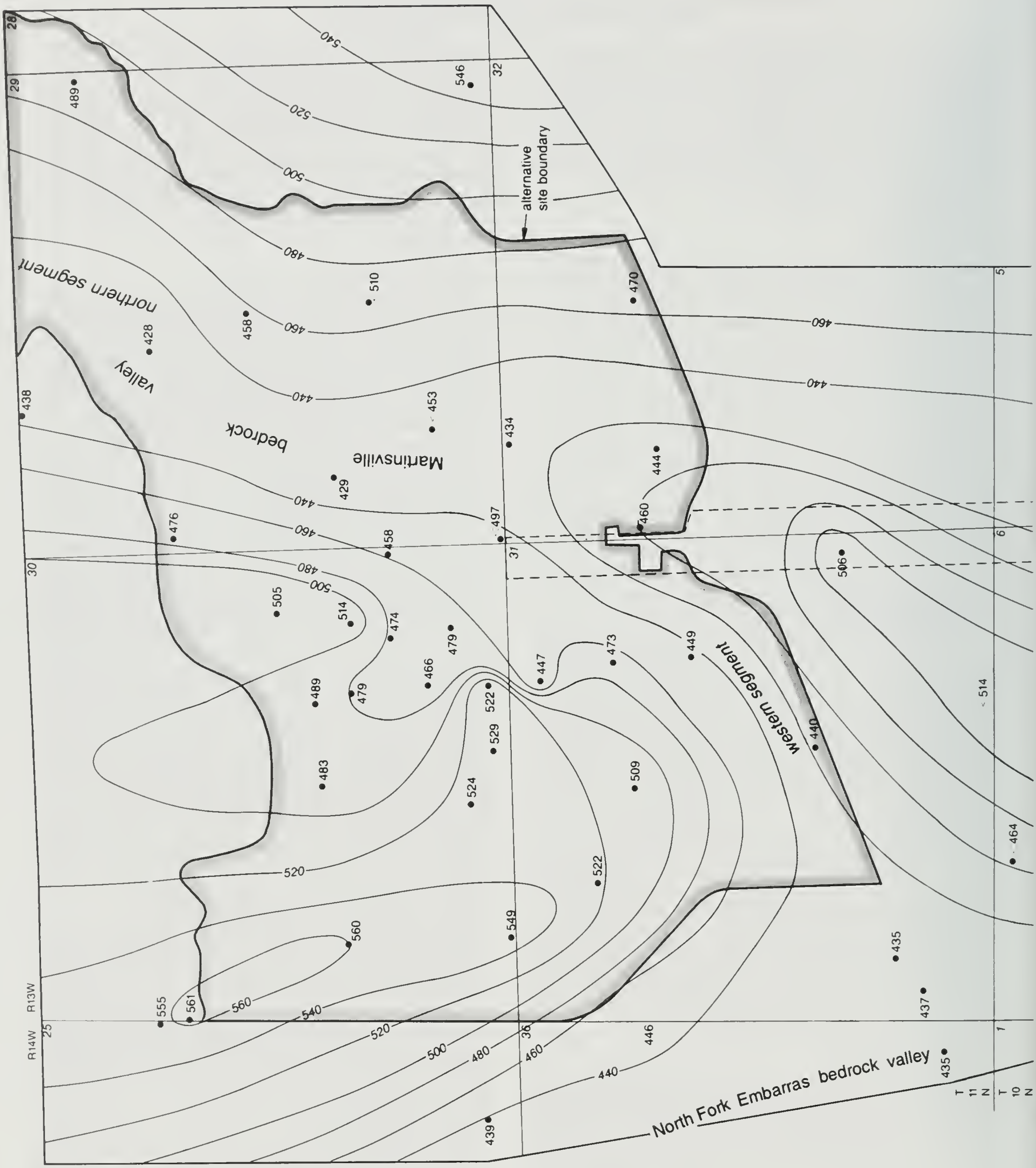
Casey Till Member

Ford (1970) informally described and named the Casey till member of the Banner Formation, but Kettles (1980) correlated the unit in Clark County with the Hillery Till Member of the Banner Formation described near Danville, Illinois (Johnson et al. 1972). Because the regional distribution of the Hillery Till Member is not well known, Ford's local nomenclature was retained.

The Casey (bc in table 1) is composed of gray loam to clay loam diamicton that contains a mean grain-size distribution of 38% sand, 38% silt, and 24% clay, and a mean clay mineral composition of 8% expandables, 63% illite, and 29% kaolinite plus chlorite (appendix). The particle-size distribution of the Casey is consistent at any section, but it varies regionally (Kettles 1980). The mineralogy of the fine sand fraction (0.25 to 0.125 mm) of pre-Illinoian tills in northern Clark County indicates they were deposited by the Huron–Erie Lobe of the Laurentide Ice Sheet (Fox 1987). Sediments deposited by the Huron–Erie Lobe are differentiated from Lake Michigan Lobe deposits by a greater content of magnetic minerals, plagioclase, and calcite (Johnson 1964, Fox 1987).

Where exposed, the Casey is commonly oxidized (Kettles 1980; oxidized samples are denoted as bc–o in figs. 9, 10). The oxidized diamicton generally is yellowish brown to brown and contains irregularly oriented fractures that have sand fillings as much as 0.25 inch thick. The oxidization is considered part of the C1, C2, and/or C3 horizons of the Yarmouth Soil (soil horizon designations after Follmer 1985).

Although not observed at the MAS, the Casey till has been identified east and west of the MAS in outcrops CC–8 and CC–11 near Mill Creek, and in CC–20 north of Casey, Illinois. An accessible exposure of the Casey till member in Clark County is along Mill Creek at CC–11 (fig. 1) at or near location 7 of MacClintock (1929), where the unit is at least 15 feet thick (fig. 9). At CC–11, the upper 3 to 5 feet of the Casey is a leached, reddish brown, clay loam diamicton that contains a well developed, pedogenic subangular, blocky structure and abundant, continuous clay cutans (fig. 9). Below the leached zone is about 5 feet of oxidized diamicton that has numerous horizontal, platy joints coated with sesquioxides, and at least 3 feet of unoxidized, wood-bearing diamicton. MacClintock (1929)


alternative site boundary
northern segment
bedrock valley
Martinsville
western segment
North Fork Embarras bedrock valley
R14W
R13W
T 11 N
T 10 N

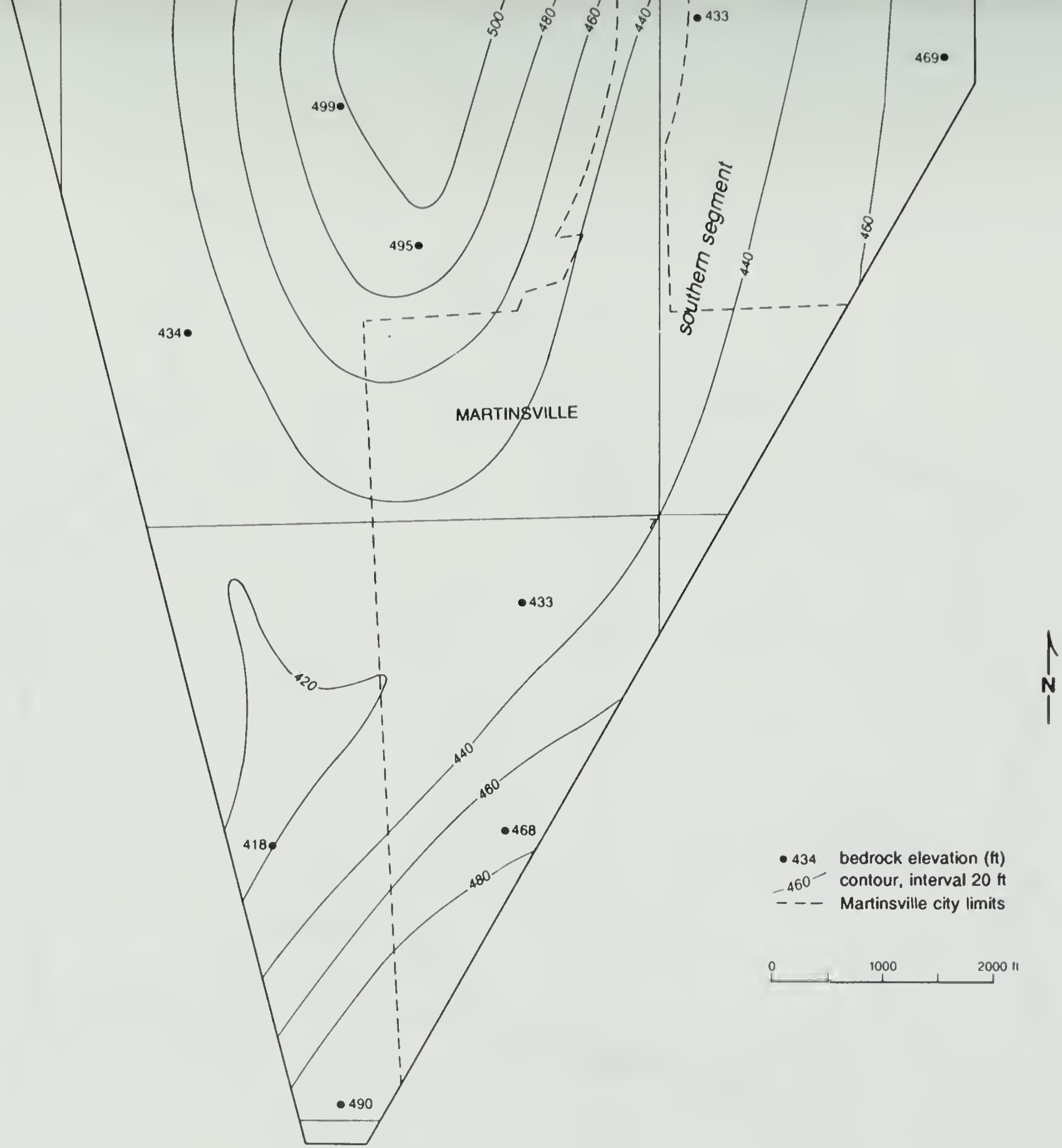
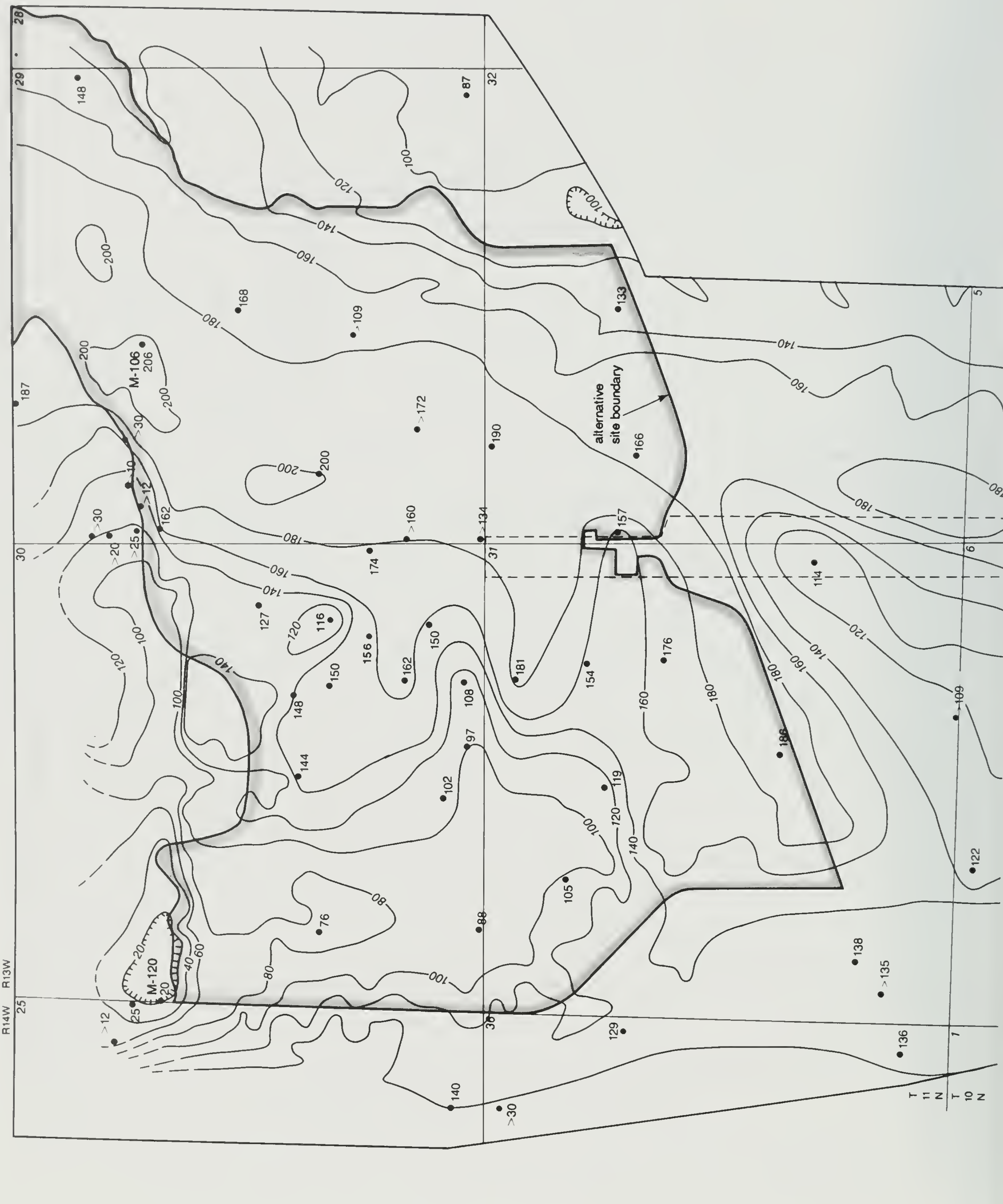


Figure 7 Bedrock topography beneath the MAS.


alternative site boundary
M-106
M-120
R14W
R13W
T 11 N
T 10 N

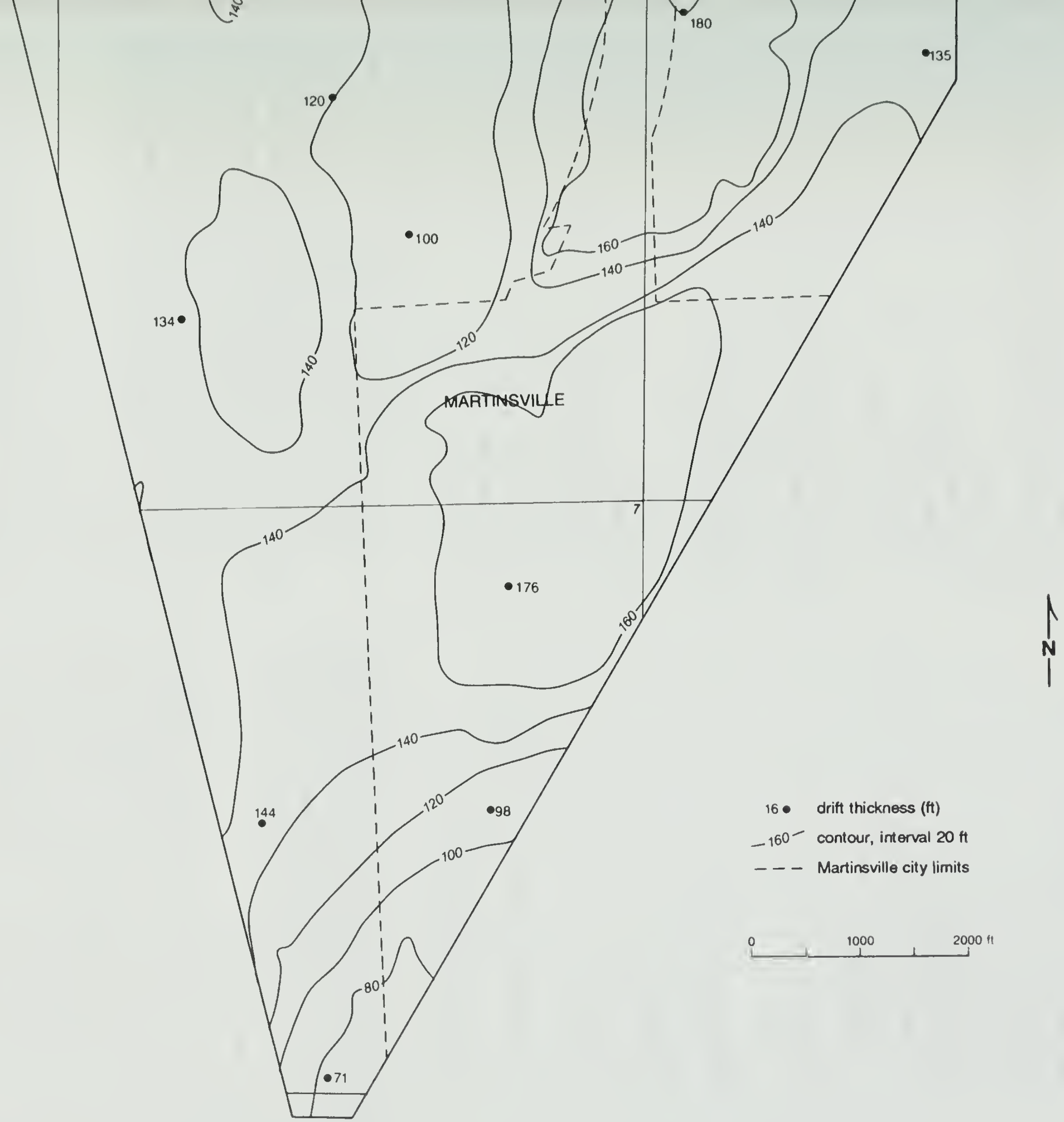


Figure 8 Thickness of glacial drift at the MAS.

Table 2 Comparison of stratigraphy used in this report and in the Battelle Memorial Institute and Hanson Engineers, Inc. report (1990a).

Battelle (1990a)	This report
Cahokia Alluvium	Cahokia Alluvium
Peyton Colluvium	Peyton Colluvium
Parkland Sand	Parkland Sand
Peoria Loess	Peoria Loess
not reported/not present at MAS	Wedron Formation
Roxana Silt	sandy silt facies of Roxana Silt
Berry Clay	Berry Clay Member of Pearl and Glasford Formations
Upper Sand	Pearl Formation
Glasford Formation	Glasford Formation
Vandalia Till Member	Vandalia Till Member
Fractured Vandalia Till	mélange facies
Vandalia Till Vandalia Sand	uniform diamicton facies
	Mulberry Grove Member
Sand Facies	silt facies, sand and gravel facies diamicton facies
	Smithboro Till Member
Smithboro Till	silt loam diamicton facies loam diamicton facies
Petersburg Silt	Petersburg Silt
	Martinsville sand
Basal Sand	sand and gravel facies
Pre-Illinoian Silt and Clay	silty clay facies diamicton facies
	Banner Formation
Pre-Illinoian Silt and Clay	Lierle Clay Member
not reported/not present at MAS	Casey till member

described 20 feet of sand and gravel above bedrock and below the diamicton, but it is not presently exposed at the outcrop. MacClintock's location 7 is the only location in Clark County where thick sand and gravel is reported to be associated with the Casey till member.

Lierle Clay Member

Willman and Frye (1970) named and described the Lierle Clay as a member of the Banner Formation in west–central Illinois. The unit is composed of soft, leached clay and silty clay diamicton that commonly becomes finer upward (bl in figs. 9, 10). The mineralogy, dominated by smectite, also contains interstratified clay minerals and no chlorite. The Lierle is interpreted to have been deposited as pedogenically altered colluvium, alluvium, or lacustrine sediment (Willman et al. 1966, Willman and Frye 1970).

Lierle Clay, as much as 8.5 feet thick, occurs at CC–8 and CC–11 east of the MAS. The sequence is composed of leached, dark gray, massive to crudely stratified, silty clay (figs. 9, 10). The material has numerous joints coated with sesquioxides, likely due to weathering at the face of the outcrop. The clay mineralogy is dominated by expandable clay minerals.

The Lierle Clay Member at the MAS was identified in core from borings M–02, M–11 and M–105. In each case, the Lierle is less than 2 feet thick, overlies bedrock, and underlies the silt diamicton facies of the Smithboro Till Member of the Glasford Formation. Thus, its stratigraphic relationship with the Martinsville sand (described below) is unknown. Battelle Memorial Institute and Hanson Engineers, Inc. (1990a) include the Lierle Clay as part of their Pre-Illinoian Silt and Clay unit (table 2).

Yarmouth Soil

The Yarmouth Soil was named by Leverett (1898), who described a buried soil from well cuttings at Yarmouth, Iowa, near the maximum extent of Illinoian glacial deposits. The Yarmouth Soil in Clark County is developed in bedrock, Lierle Clay, or the upper part of the Casey till member.

Pedogenic alteration of the Lierle Clay and the Casey till member at CC–11 resulted in a leached zone

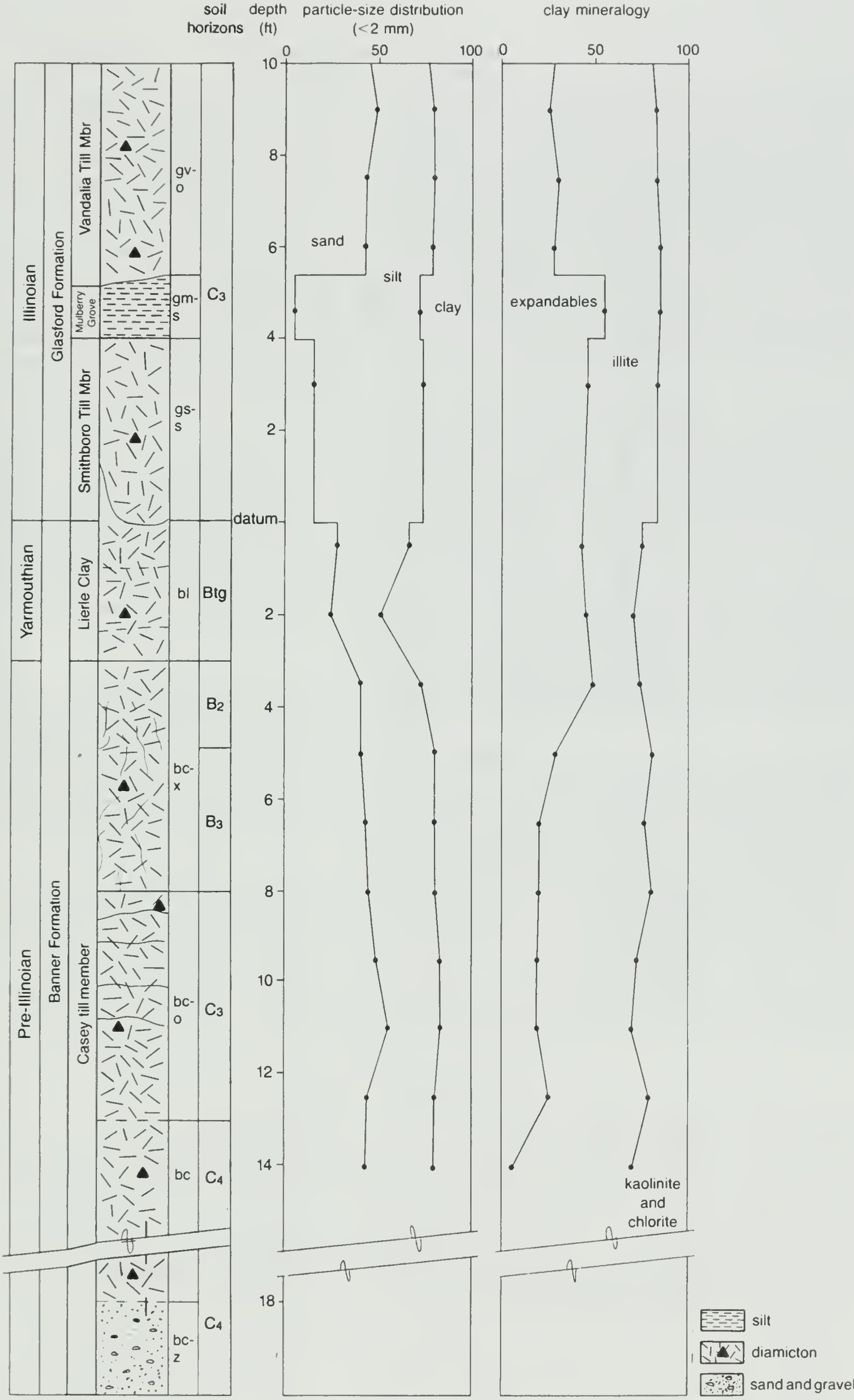


Figure 9 Lithofacies log and laboratory data from outcrop samples collected at CC–11. Location shown in figure 1.

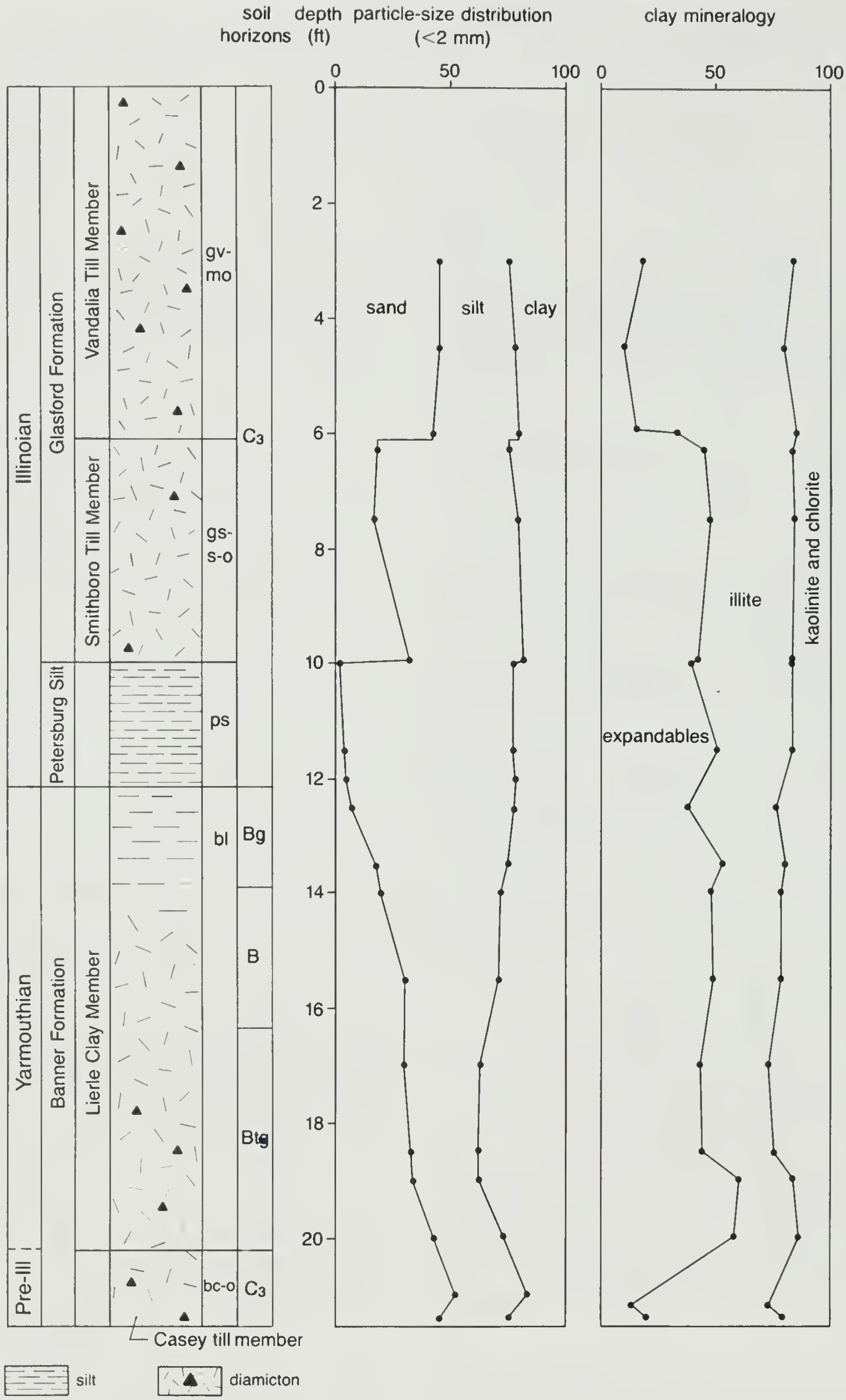


Figure 10 Lithofacies log and laboratory data from outcrop samples collected at CC–8. Location shown in figure 1.

6 to 8 feet thick and an oxidized zone 5 feet thick (fig. 9). The upper Yarmouth (B horizon) at this site is reddish and has subangular, blocky structure and continuous, thick, clay cutans. Diapiric intrusions of Lierle Clay into the overlying Smithboro Till Member suggest that the upper 3 feet of the Yarmouth Soil was affected by soft sediment deformation, perhaps due to glaciotectonic deformation or loading. Lierle Clay, corresponding to the Btg horizon of the Yarmouth Soil, contains 34% to 48% clay compared with 19% clay in the oxidized or unaltered Casey diamicton below. The clay fraction contains abundant interstratified expandable clay minerals and no chlorite, and shows an upward decrease of illite, all characteristics of material that was weathered in an interglacial pedogenic environment (Willman et al. 1966).

The lower Yarmouth (C horizon) is composed of oxidized, sandy, and jointed material. The only clay-mineral alteration is the transformation of chlorite to a vermiculitic phase that partly expands in an atmosphere saturated with ethylene glycol (Willman et al. 1966). Whereas the contact between the B and C horizons is gradational, the contact between the C horizon and unaltered Casey diamicton (the C4 horizon of Follmer 1985) is abrupt.

Martinsville Sand

The Martinsville sand is an informal lithostratigraphic unit at the MAS that occurs above bedrock and below either the Petersburg Silt or the Glasford Formation. The unit also was identified in CLK–03–01 south of Martinsville (fig. 1). Pedogenic features, described below, suggest that the Martinsville sand is younger than the Lierle Clay, although no contacts between the units were observed.

The Martinsville sand has three distinct intercalated facies that occur in varying stratigraphic order and consist chiefly of thick and continuous sand and gravel, less diamicton, and silty clay (ms–z, ms–d, and ms–s on figs. 3, 11–16, especially fig. 12). Battelle Memorial Institute and Hanson Engineers, Inc. (1990a,b,c) referred to the sand and gravel facies as the Basal Sand (table 2) and included the other two facies of the Martinsville sand as part of their Pre-Illinoian Silt and Clay unit.

Sand and gravel facies The sand and gravel facies of the Martinsville sand (ms–z in table 1) is as much as 30.8 feet thick at M–06 (fig. 17). The unit occurs persistently in borings that penetrate glacial drift below an elevation of 490 feet in the lowest portions of the buried bedrock valleys. The sand and gravel facies may be continuous along the Martinsville and North Fork Embarras bedrock valleys. A bed of mostly well sorted, fine grained sand, about 3 feet thick and containing coniferous wood fragments, occurs in boring CLK–02–02 (fig. 18).

Thin layers in the sand and gravel facies of the Martinsville sand are cemented with sesquioxides. The genesis of the cemented zones probably is related to the reduction of iron and manganese that may have occurred in wetland pedogenic or diagenetic environments. Negligible pedogenic structure and the presence of dolomite and chlorite favor a diagenetic origin. Also supporting a diagenetic origin of these cements is the relative abundance of reduced iron and manganese species, dissolved carbon, and methane in groundwater from the Martinsville sand (Battelle Memorial Institute and Hanson Engineers, Inc. 1990b). A 3-day aquifer test indicated hydrological continuity of the sand and gravel facies of the Martinsville sand along the northern segment of the Martinsville bedrock valley (Battelle Memorial Institute and Hanson Engineers, Inc. 1990b). The hydrological continuity of the Martinsville sand along and between the other segments of bedrock valleys was not tested.

Diamicton facies The diamicton facies (ms–d), as much as 9 feet thick at CLK–02–03, is the least common facies of the Martinsville sand. A distinctive olive green color (5Y 4/2, Munsell notation) and a mineralogy rich in kaolinite plus chlorite differentiate this unit from other diamicton units at the MAS; particle-size distribution varies and is not diagnostic.

The facies is generally leached or slightly dolomitic. The provenance of the coarse fragments is mostly local bedrock, but pebbles composed of quartz, quartzite, and polymineralogic lithologies with provenance from the upper Great Lakes or Canadian Shield, suggest that some of the material is reworked from pre-Illinoian glacigenic sediment.

Silty clay facies The texture of the silty clay facies (ms–s) ranges from loam to clay, but it is silty clay at most places. Uncommon, thin interbeds of fine to medium grained sand occur within the silty clay. The unit is as much as 4 feet thick at boring CLK–03-01, but it is generally thin or absent. In core, this facies has contrasting colors, including mottles of greenish gray (5GY 6/1, Munsell notation) and red (10R 4/6). Clay content, as much as 76% (fig. 18), is the greatest measured for any geologic unit described in this study. As with the diamicton facies, the silty clay facies contains more kaolinite plus chlorite relative to other units at the MAS (appendix). The silty clay facies commonly overlies the sand and gravel facies.

Petersburg Silt

Willman et al. (1963) described and named the Petersburg Silt (ps in table 1). At the MAS, it is composed of brown, laminated (often rhythmically) or uniform, fossiliferous silt loam and less commonly, well sorted, very fine to coarse grained sand. The Petersburg occurs below an elevation of about 505 feet in the bedrock valleys, where it is as much as 50.4 feet thick at M–125, the thickest known occurrence of this unit in Illinois. Mean thickness at the MAS is 5.7 feet. East and south of the MAS, the Petersburg is generally absent or less than about 2 feet thick, as at exposure CC–8 (ps in fig. 10). The mean grain-size distribution is 11% sand, 67% silt, and 22% clay (appendix). The semiquantitative mineralogical analyses of the <2 µm fraction show that the

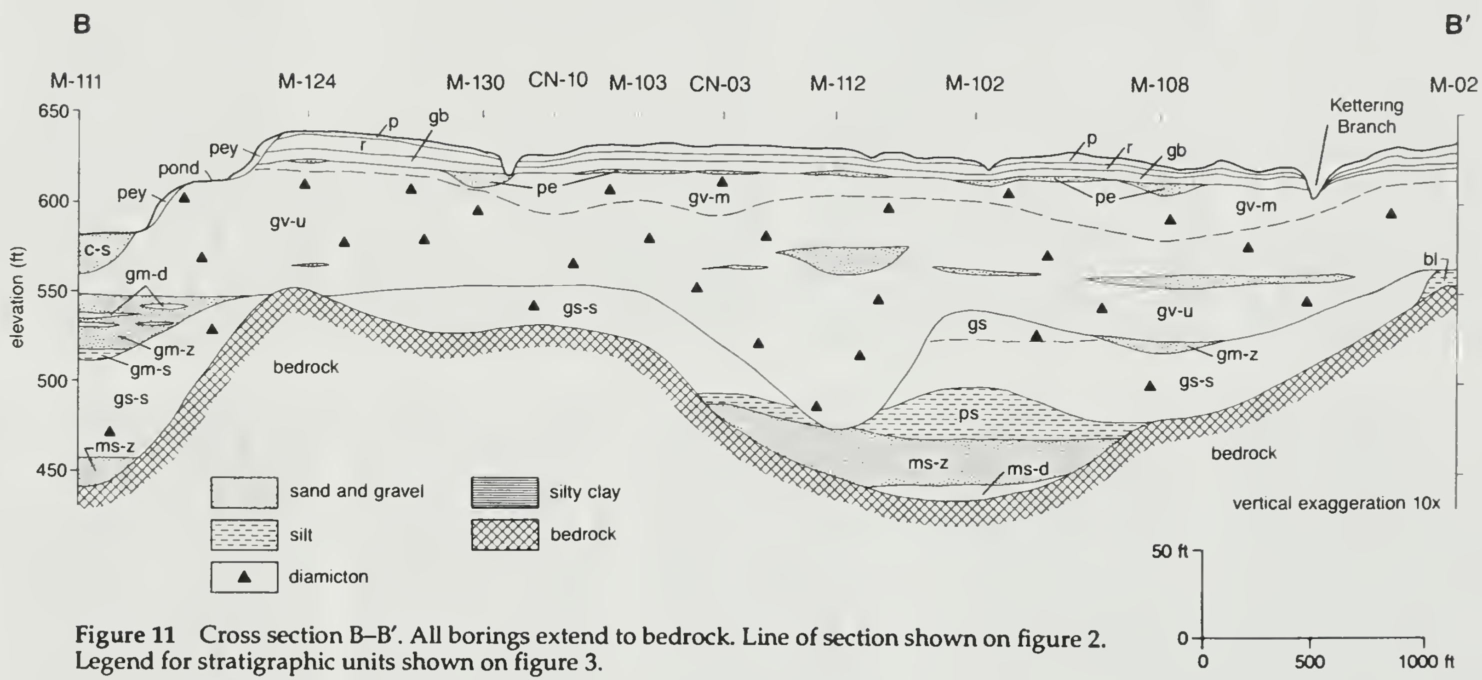


Figure 11 Cross section B–B′. All borings extend to bedrock. Line of section shown on figure 2. Legend for stratigraphic units shown on figure 3.

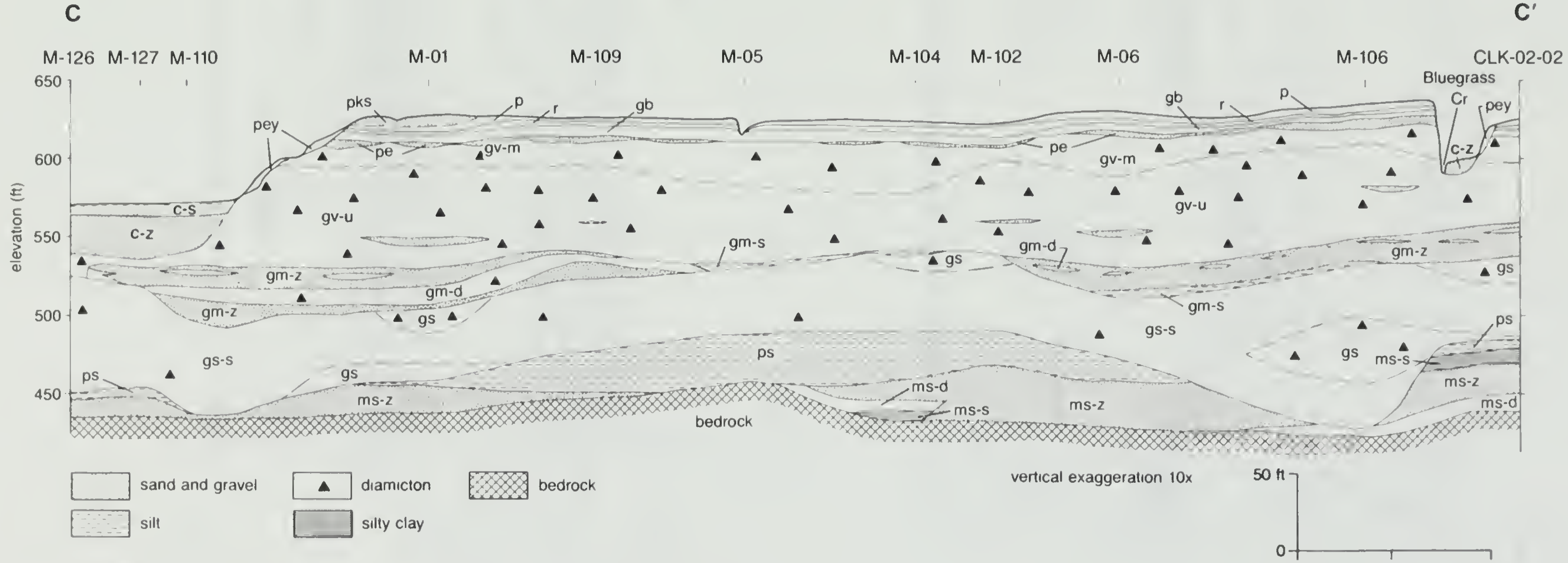


Figure 12 Cross section C–C′. All borings extend to bedrock except M–127.

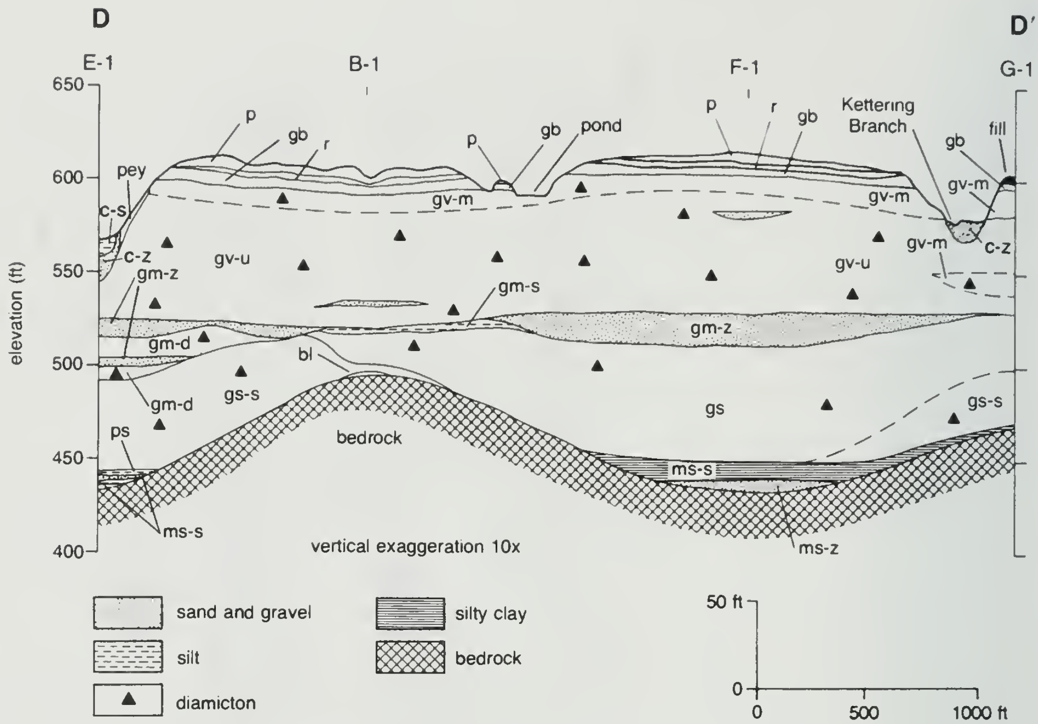


Figure 13 Cross section D–D′. All borings extend to bedrock.

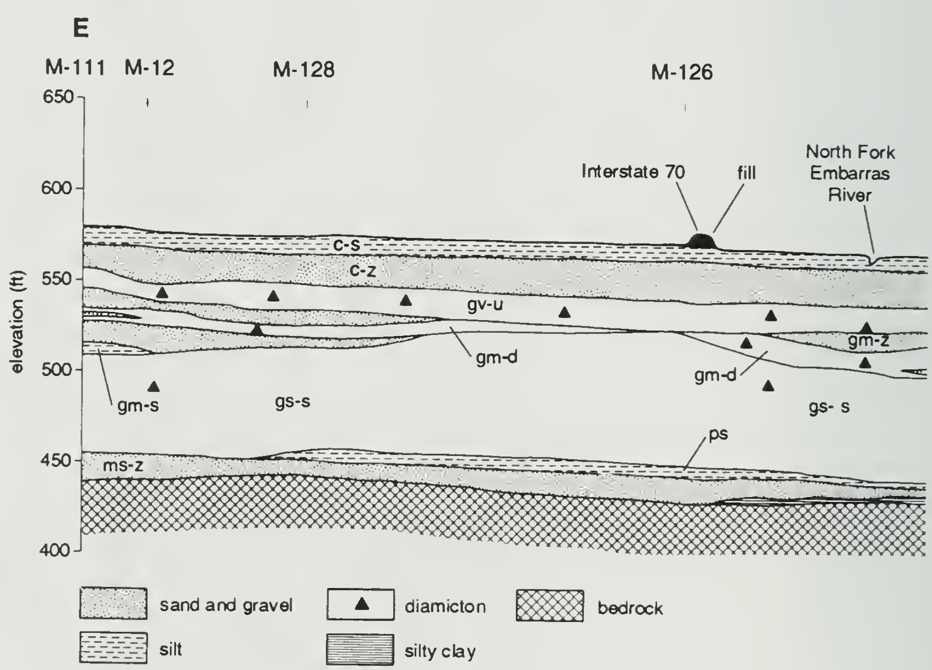


Figure 14 Cross section E–E′. All borings extend to bedrock.

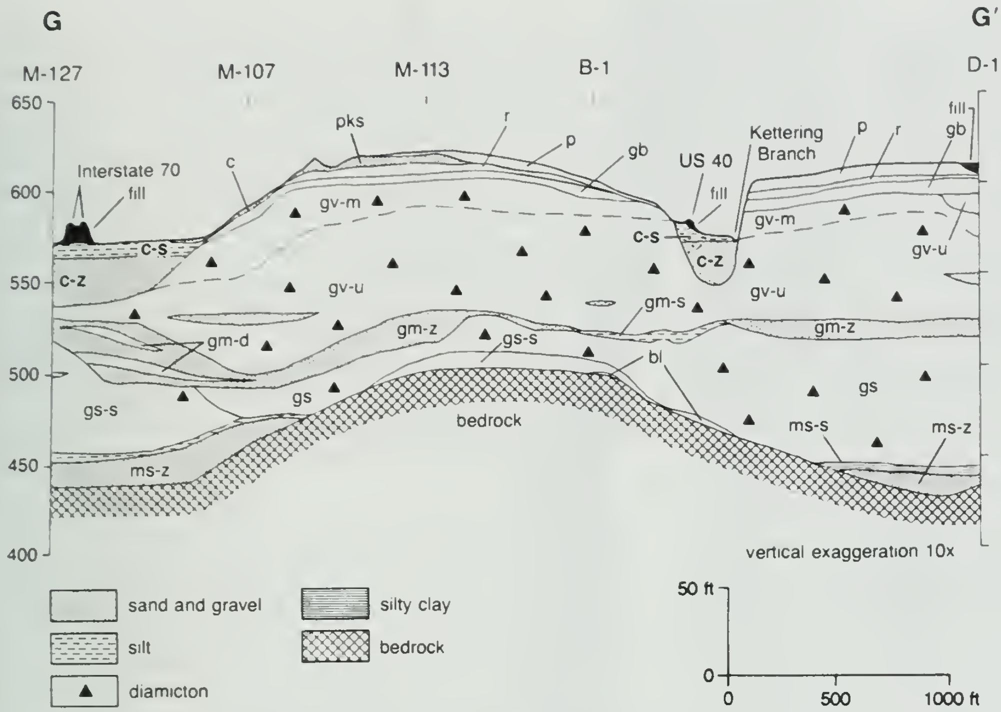
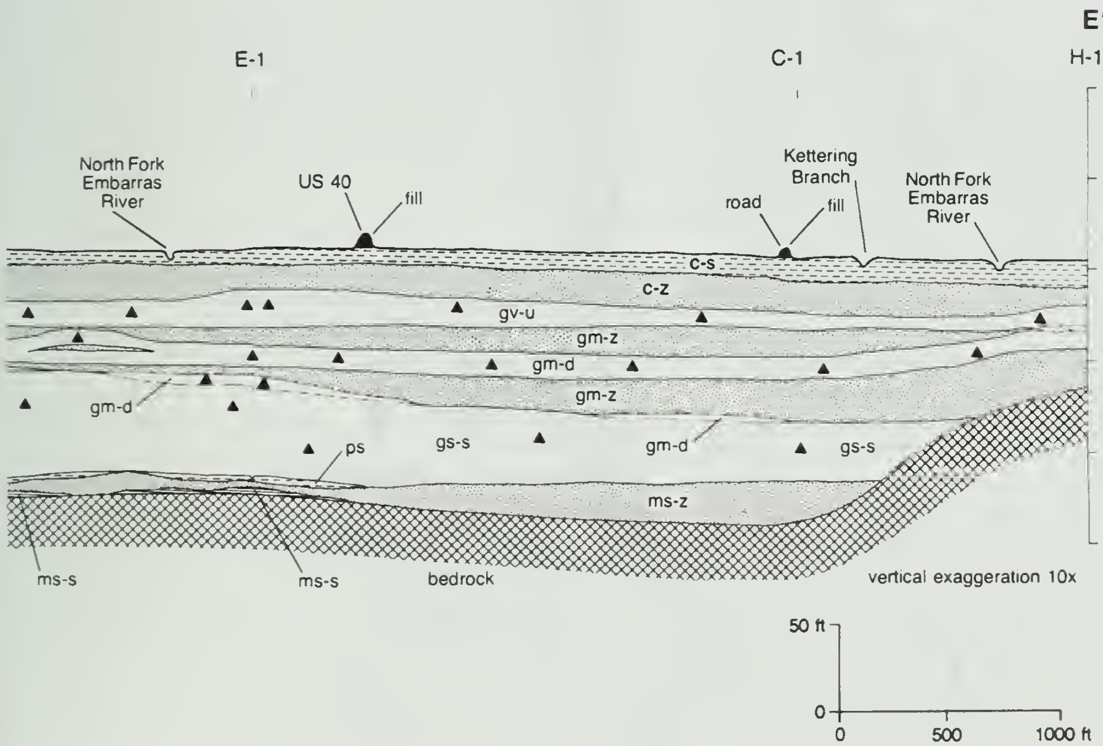


Figure 16 Cross section G–G′. All borings extend to bedrock.



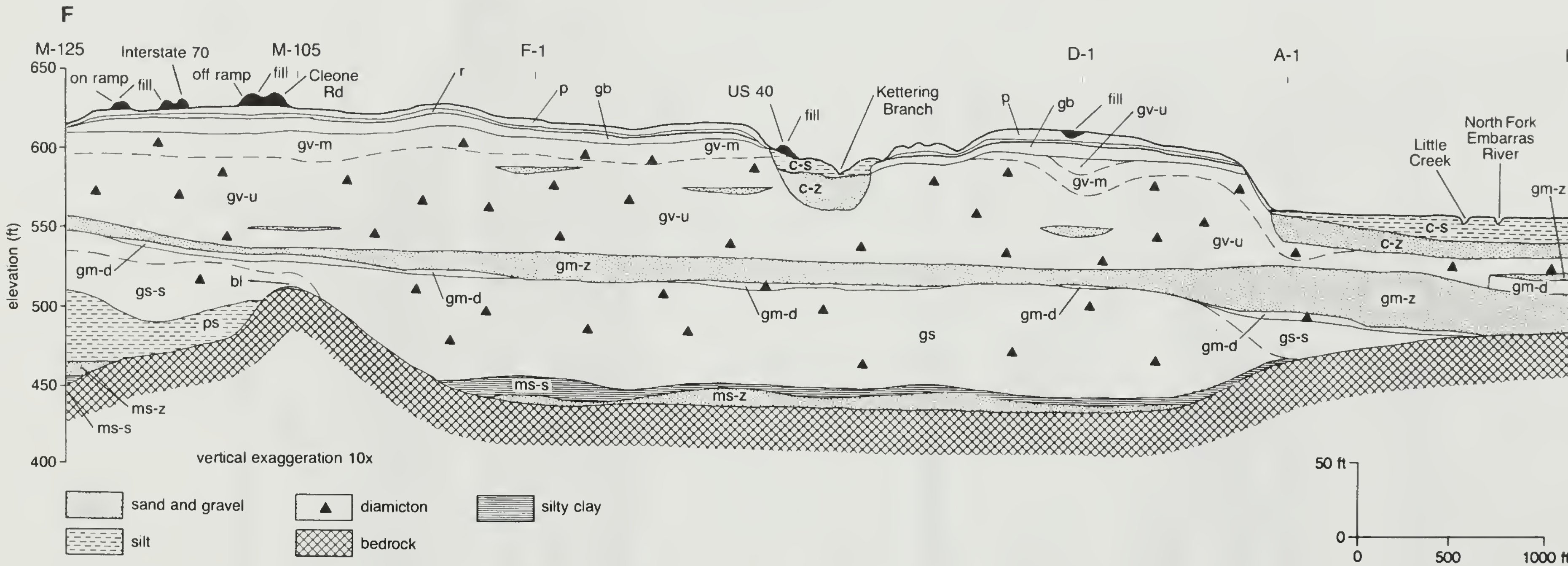


Figure 15 Cross section F–F′. All borings extend to bedrock.

mean composition of the Petersburg is 19% expandables, 52% illite, and 29% kaolinite plus chlorite; unoxidized samples are composed of about 12% expandables, 57% illite, and 31% kaolinite plus chlorite. The unit contains abundant coniferous wood fragments and a few gastropod shells, including *Stenotrema*, *Hendersonia*, and *Succinea* (Barry Miller, Kent State University, personal communication 1989). Inclusions of the Petersburg commonly occur in the silt loam diamicton facies of the Smithboro Till Member of the Glasford Formation. Pedogenic alteration of the Petersburg is restricted to a few leached layers of peat that possess silt coatings on platy peds, and abundant root traces. Associated with these organic-bearing layers are bubble impressions probably caused by methanogenesis.

Glasford Formation

The Glasford Formation, named and described by Willman and Frye (1970), has four members in north-central Clark County. In ascending order, the members are the Smithboro Till, Mulberry Grove, Vandalia Till and Berry Clay. These units overlie the Banner Formation, Martinsville sand, and Petersburg Silt, and underlie the Pearl Formation, Peyton Colluvium, and Cahokia Alluvium. Jacobs and Lineback (1969) initially described the glacigenic members of the Glasford Formation east of the Illinois River near Vandalia, Illinois. In this report, the Berry Clay, normally an upper member of the Glasford Formation, includes soft, gleyed diamicton at the top of the Pearl Formation. The Glasford is at least 180.4 feet thick at M–106 in the MAS buried valley; about 30 feet is exposed in several outcrops adjacent to and east of the study area. The Glasford is thinnest and locally absent below modern valley floors, such as at M–120 at the mouth of Bluegrass Creek (fig. 3).

Smithboro Till Member

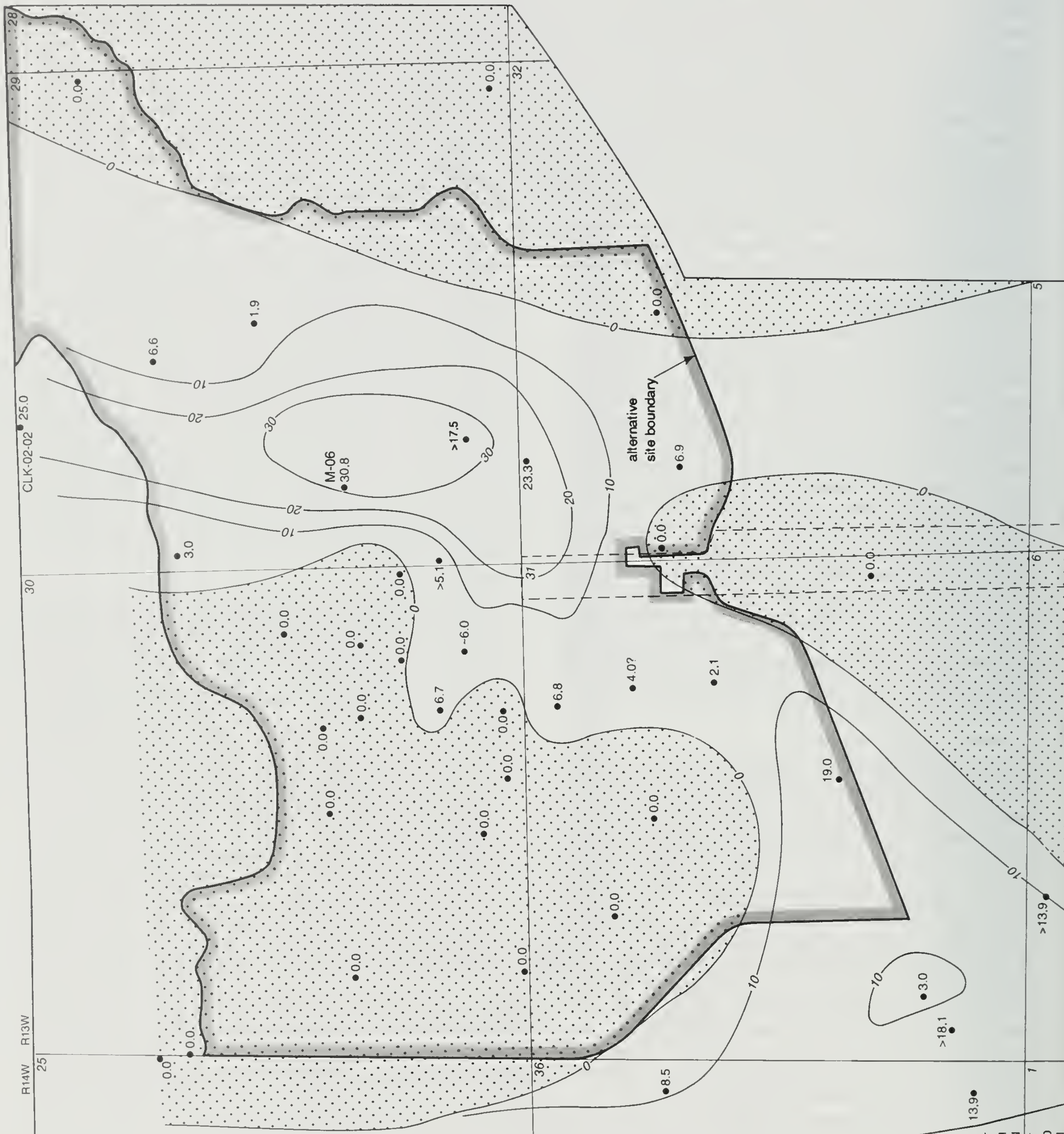
At the MAS, the Smithboro Till Member of the Glasford Formation is composed of silt loam to loam diamicton and commonly contains wood fragments and sparse gastropod shells, especially where the diamicton is silty. The mineralogy of the fine grained sand fraction indicates that the Smithboro Till Member was deposited by the Lake Michigan Lobe of the Laurentide Ice Sheet (Fox 1987). The Smithboro is not exposed at ground surface at the MAS, but it is as much as 97 feet thick in the Martinsville bedrock valley at boring M–106 (fig. 19), the thickest occurrence yet described in Illinois. Mean thickness of the Smithboro is 28 feet at the MAS. Elsewhere in Illinois, the Smithboro is not known to exceed a thickness of about 10 feet. The Smithboro is composed chiefly of diamicton, but layers of sand and gravel were encountered in several of the 67 borings that penetrated the Smithboro. The Smithboro truncates the Petersburg Silt and Martinsville sand at several localities under the MAS (figs. 12, 15).

An arbitrary textural boundary differentiates two diamicton facies of the Smithboro. Approximately 63% of the Smithboro diamicton samples contains 25% or less sand, and is assigned to the silt loam diamicton facies. The remaining 37% of the samples contains more than 25% sand, and is assigned to the loam diamicton facies. The mean texture and standard deviation of the combined Smithboro diamicton facies is $23.1 \pm 8.0\%$ sand, $51.9 \pm 9.8\%$ silt, and $24.8 \pm 5.9\%$ clay; clay mineralogy is $26.2 \pm 9.7\%$ expandables, $45.4 \pm 7.3\%$ illite, and $28.3 \pm 6.1\%$ kaolinite plus chlorite (appendix). Figure 20 shows the textural and clay mineralogical variability of the two Smithboro facies. Figure 21 shows composite plots for all diamictons at the MAS, and the variability of the Smithboro compared with other units at the MAS. By comparison, the Vandalia Till Member has a relatively uniform texture and mineralogy.

The silt loam diamicton facies (gs–s in appendix) has inclusions of abundant wood fragments, uniform and laminated silt, and gleyed sandstone. Sparse gastropod shells and folded beds and laminae of silt and silty clay are present. Composition of the inclusions indicates they are redeposited gleyed bedrock, Petersburg Silt, and silty clay facies of the Martinsville sand. The silt loam diamicton facies is as much as 58 feet thick at boring M–03. The unit has a mean grain-size distribution of 18% sand, 57% silt, and 25% clay, and a mean clay mineral composition of 29% expandables, 43% illite, and 28% kaolinite plus chlorite (appendix). The silt loam diamicton facies is commonly overlain by or interbedded with the loam diamicton facies (gs in table 1, appendix).

The loam diamicton facies is as much as 44 feet thick at boring M–02. The unit has a mean grain-size distribution of 31% sand, 44% silt, and 25% clay, and a mean clay mineral composition of 23% expandables, 49% illite, and 28% kaolinite plus chlorite (appendix). The two facies of the Smithboro have markedly different physical properties reflecting the difference in clay and silt content. The mean moisture content, for example, is 17.3% for the silt loam diamicton facies and 13.1% for the loam diamicton facies (Curry and Troost 1991).

Segments of the bedrock valleys are filled primarily with one or the other facies of the Smithboro Till Member. For example, loam diamicton is the dominant facies of the Smithboro in the southern segment of the Martinsville bedrock valley (e.g., boring D-1, fig. 22), but the silt loam facies is dominant in the North Fork Embarras Bedrock Valley (figs. 14, 23). Because of similar lithologic characteristics, differentiating the Smithboro loam diamicton facies from the overlying Vandalia Till Member is difficult without laboratory data or the intervening Mulberry Grove Member. In some bedrock valley segments, the grain-size distribution in some borings gradually coarsens upwards, as shown by the data from CLK–02–02 (fig. 18). At other locations, abrupt changes occur from one facies to another, such as in the cores from borings M–07 (fig. 24) and M–106 (fig. 25). The abrupt contacts are interpreted to be shear planes caused by deformation and inclusion of Petersburg Silt or the silt loam diamicton facies within the loam diamicton facies of the Smithboro.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CLK-02-02
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M-06
30.8
>17.5
23.3
6.9
6.6
1.9
3.0
>5.1
~6.0
6.7
6.8
4.0?
2.1
19.0
3.0
>18.1
>13.9
13.9
8.5
15.7
R14W
R13W
T 11 N
T 10 N
28
29
32
5
30
31
6
25
36
1

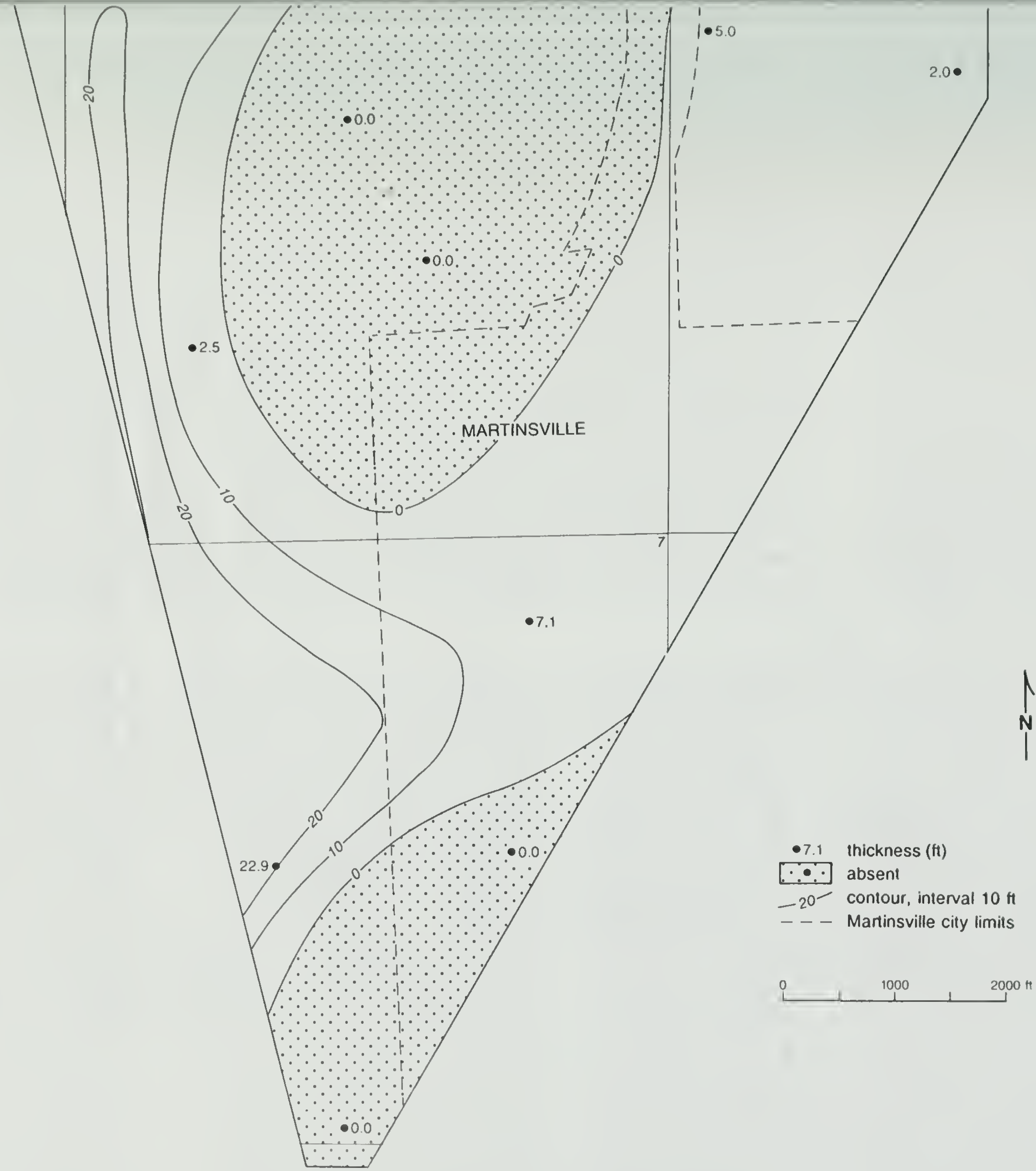


Figure 17 Thickness of the sand and gravel facies of the Martinsville sand.

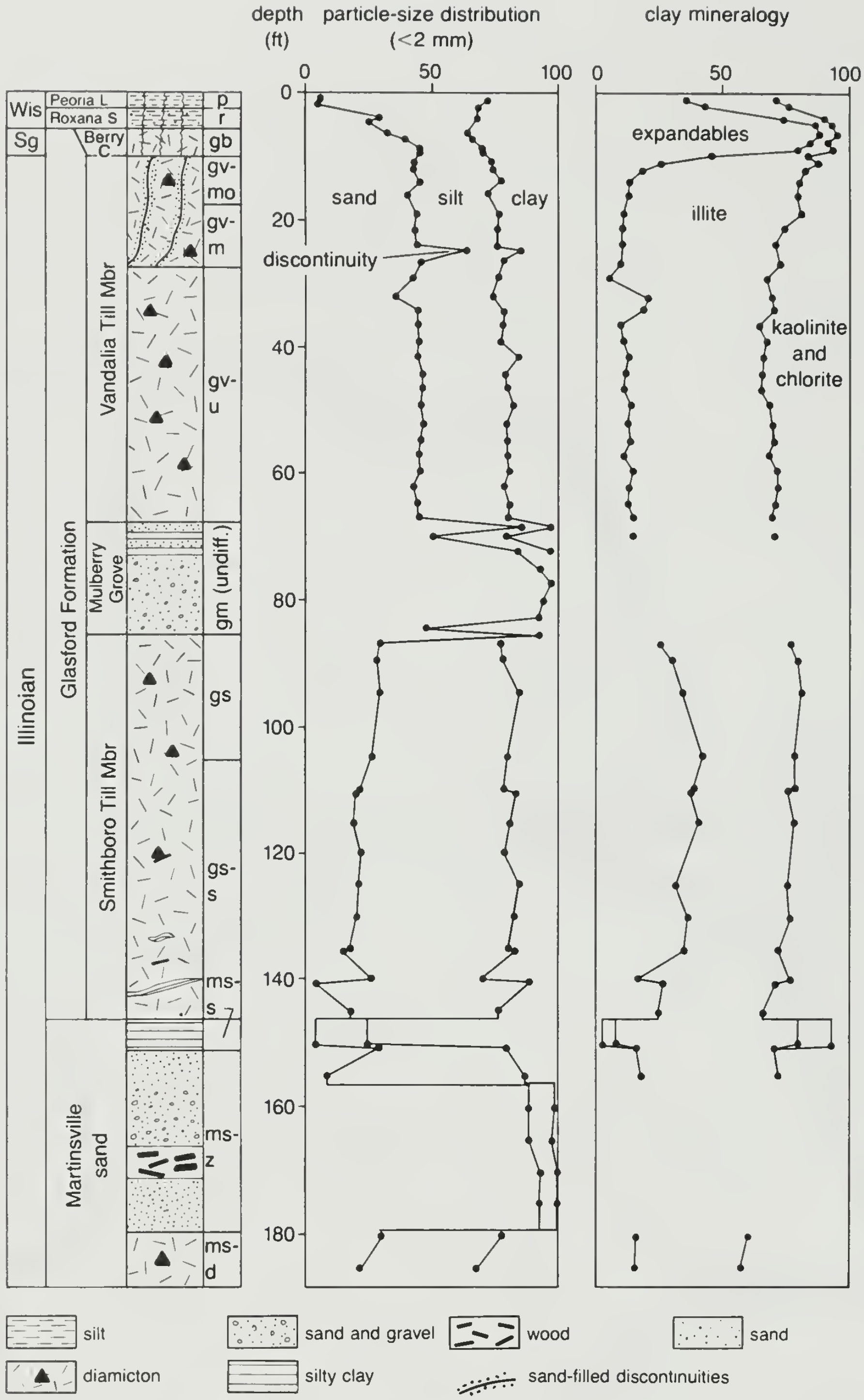


Figure 18 Lithofacies log and laboratory data from samples of core CLK–02–02. Location shown in figure 2.

Kettles (1980) correlated units in the area with the Smithboro and Fort Russell till members, which were originally described in the East St. Louis area by McKay (1979). The Smithboro and Fort Russell units have lithologic properties similar to those of the silt loam diamicton and loam diamicton facies, respectively, described above for the Smithboro (table 3). The gradational physical properties and contacts between the facies, and the repetition of facies in some borings (figs. 24, 25) indicate that the two facies probably are contemporaneous. The Fort Russell till member is, therefore, not recognized at the MAS. Regionally, Kettle's Fort Russell unit may correlate with the lower part of the uniform diamicton facies of the Vandalia Till Member, described below. Data in table 3 indicate that the silt loam diamicton facies of the Smithboro at the MAS contains about 10% less expandable clay minerals and about 7% more silt than the Smithboro as described in other studies. These differences likely reflect a larger component of Petersburg Silt reworked within the Smithboro at the MAS.

Mulberry Grove Member

The Mulberry Grove Silt Member was described by Jacobs and Lineback (1969) and formally named and assigned to the Glasford Formation by Willman and Frye (1970). In the study area, the Mulberry Grove is as much as 58 feet thick at boring C–1 (fig. 26), and comprises three easily distinguishable facies composed of sand and gravel, diamicton, and silt loam. Because the sand and gravel facies is dominant at the MAS, silt is dropped from the name in this report. Regional distribution of the Mulberry Grove Member is not well known; sediments equivalent to the sand and gravel facies and the silt facies were described in the type area near Vandalia, Illinois (Jacobs and Lineback 1969) and in Coles County, Illinois (Johnson et al. 1972, Ford 1970).

Battelle Memorial Institute and Hanson Engineers, Inc. (1990b) considered the Mulberry Grove to be a moderate-yielding aquifer. An approximate north-south regional flow pattern is indicated by hydrological data. The City of Martinsville draws water from this aquifer, as well as from shallower water-bearing units. The municipal wells are located southwest of the town of Martinsville, which is adjacent to the North Fork Embarras River valley (fig. 2).

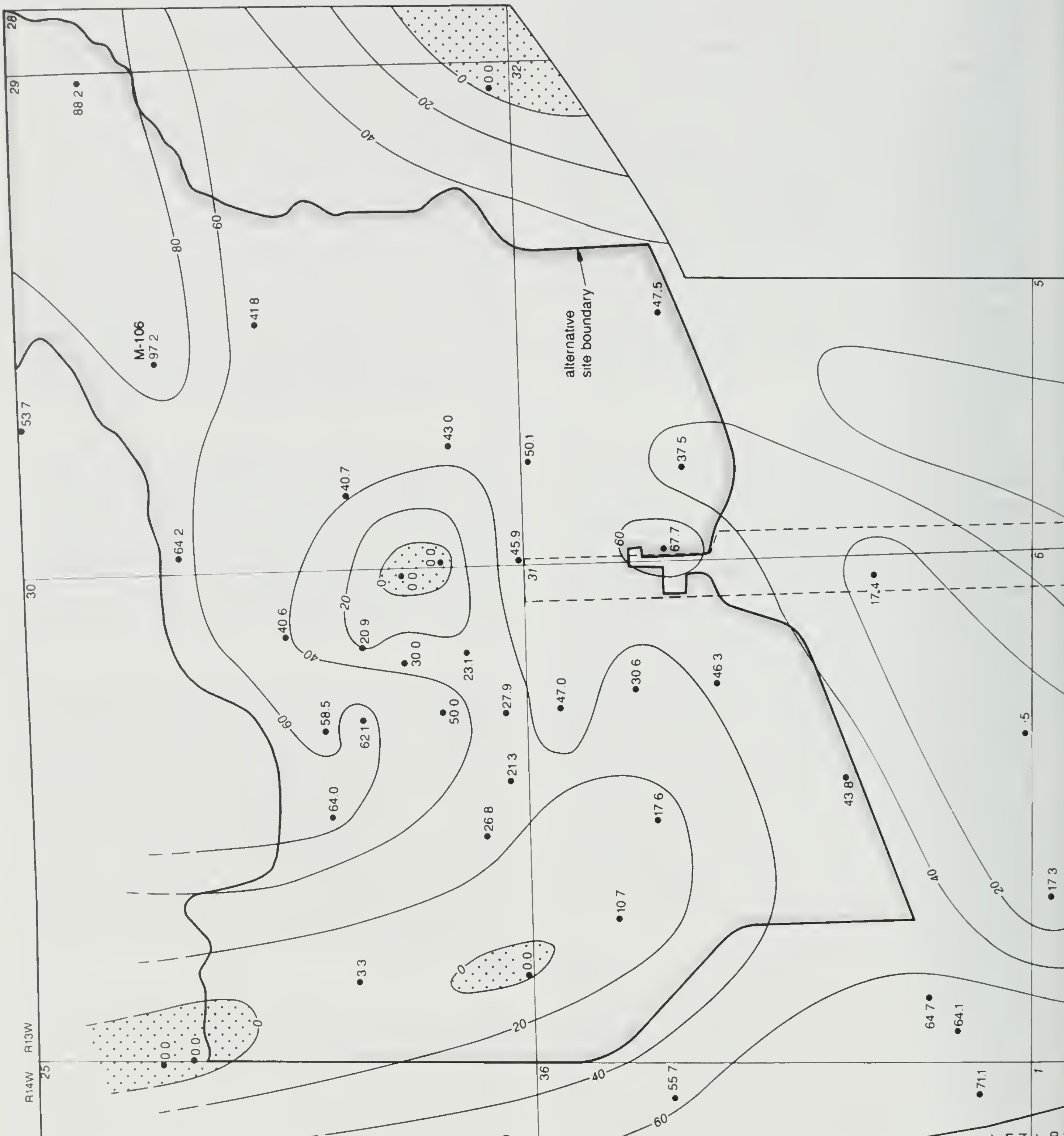
The Mulberry Grove Member, as much as 31 feet thick under the MAS, is thicker adjacent to the MAS in the North Fork Embarras River valley at borings C–1 (58 ft), M–110 (32 ft), and M–111 (36 ft; fig. 26). In general, the Mulberry Grove Member of this report corresponds to the Sand Facies described by Battelle Memorial Institute and Hanson Engineers, Inc. (1990a, b, c; table 2). The Mulberry Grove, encountered in 62 of the 76 borings that penetrated this stratigraphic interval, averages 17.8 feet thick.

A persistent layer of the diamicton facies is sandwiched by the sand and gravel facies of the Mulberry Grove along the North Fork Embarras River buried valley (fig. 14, cross section E–E′). Differing geochemical and piezometric data from the sand and gravel layers that overlie and underlie the diamicton (Battelle Memorial Institute and Hanson Engineers, Inc. 1990b) support the interpretation that the diamicton layer is laterally continuous. These data indicate that groundwater in the upper sand and gravel unit interacts with groundwater in the Cahokia Alluvium, whereas groundwater in the lower sand and gravel layer is geochemically distinct and does not readily interact with the Cahokia. The continuous diamicton and thick sand and gravel layers occupy a paleochannel eroded in the Smithboro Till Member along the North Fork Embarras bedrock valley (fig. 27). The channel morphology is evident in a segment of cross section C–C′, which is drawn perpendicular to the buried valley axis through borings M–126, M–127, and M–110 (fig. 12). Because of the general coincidence of the North Fork Embarras River valley and its buried bedrock valley counterpart, a thick sand and gravel facies likely occurs in this channel along any cross-valley profile of the modern North Fork Embarras River valley in the study area.

Sand and gravel facies The sand and gravel facies (gm–z in table 1) is composed of well sorted, fine to coarse grained sand, and less sorted sand and gravel, and sandy loam. The facies, as much as 35 feet thick under the east half of the North Fork Embarras River valley, is commonly interbedded with thin layers of the diamicton facies (fig. 23). A thick sand and gravel facies also occurs in the northeast part of the MAS (fig. 28).

Diamicton facies The diamicton facies (gm–d) is composed of beds of gray loam to clay loam diamicton less than 12 feet thick. The diamicton facies generally is interbedded with the sand and gravel facies or in contact with the Smithboro Till Member. The mean clay mineral composition of the diamicton facies is 12% expandables, 60% illite, and 28% kaolinite plus chlorite, which is nearly identical to the clay mineral composition of the overlying Vandalia Till Member (fig. 21). At D–1, the diamicton facies is soft and gleyed, and is interpreted as a Bg soil horizon of the Pike Soil, a pedostratigraphic unit that has been described at several localities in central Illinois (Johnson et al. 1972, Fox 1987).

Silt facies The silt facies of the Mulberry Grove Member (gm–s) consists of silty sediment that is gray, yellowish brown, or locally black, organic rich, and leached or weakly calcareous. The clay mineralogy of the silt facies is nearly identical to that of the underlying Smithboro Till Member (e.g., fig. 24). Less common than the organic rich silts are thin beds of gray, uniform calcareous silt associated with the diamicton facies. The clay mineralogy of these beds is nearly identical to the clay mineralogy of the diamicton facies and the overlying Vandalia Till Member. The silt facies, generally less than 1 foot thick at the MAS, is as much as 10 feet thick


M-106
alternative
site boundary
R14W
R13W
T
11
N
T
10
N

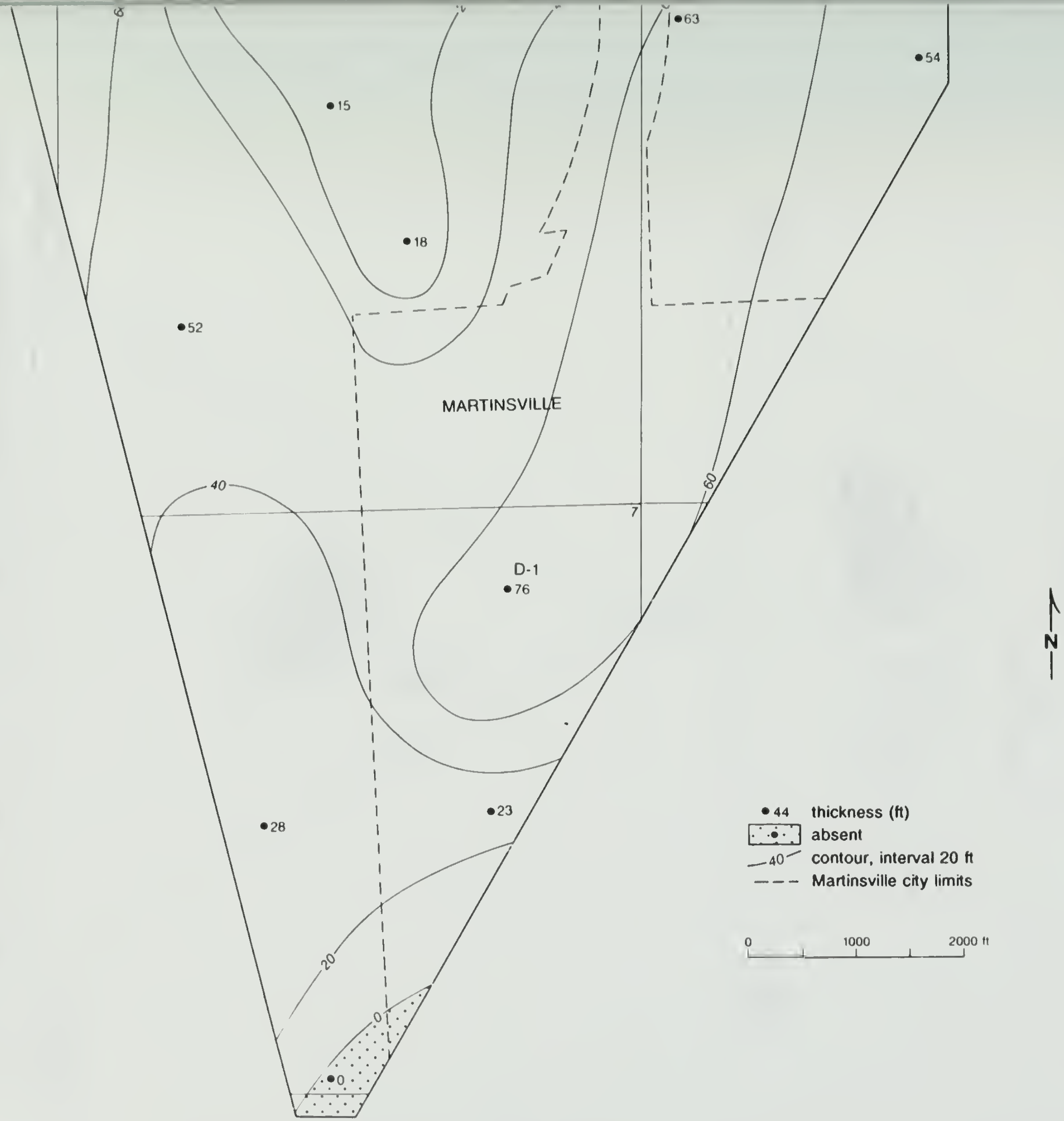


Figure 19 Thickness of the Smithboro Till Member, Glasford Formation.

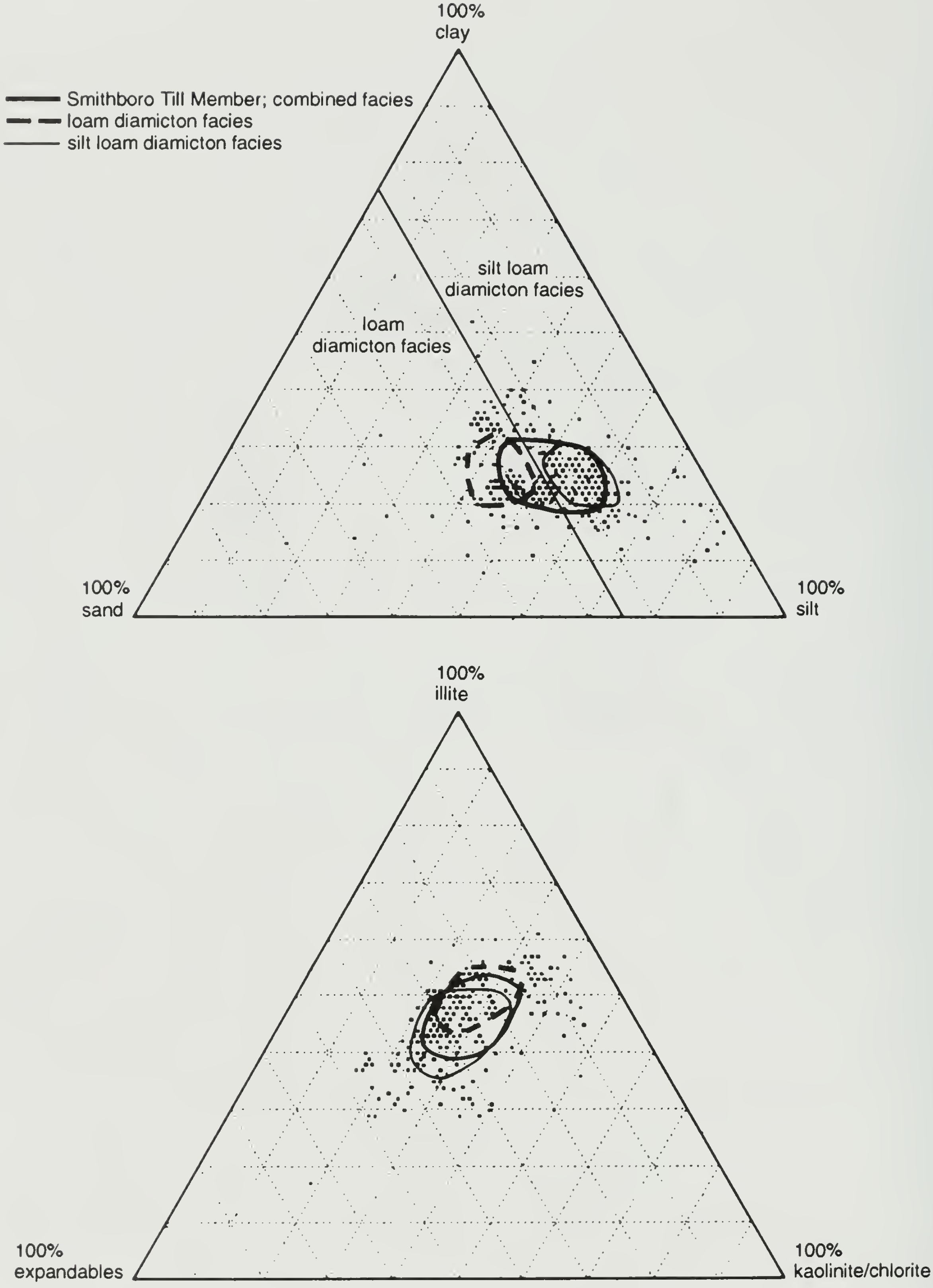


Figure 20 Ternary plots of textural and mineralogical data for the Smithboro Till Member. The envelopes encompass values within 1 standard deviation of the mean (appendix).

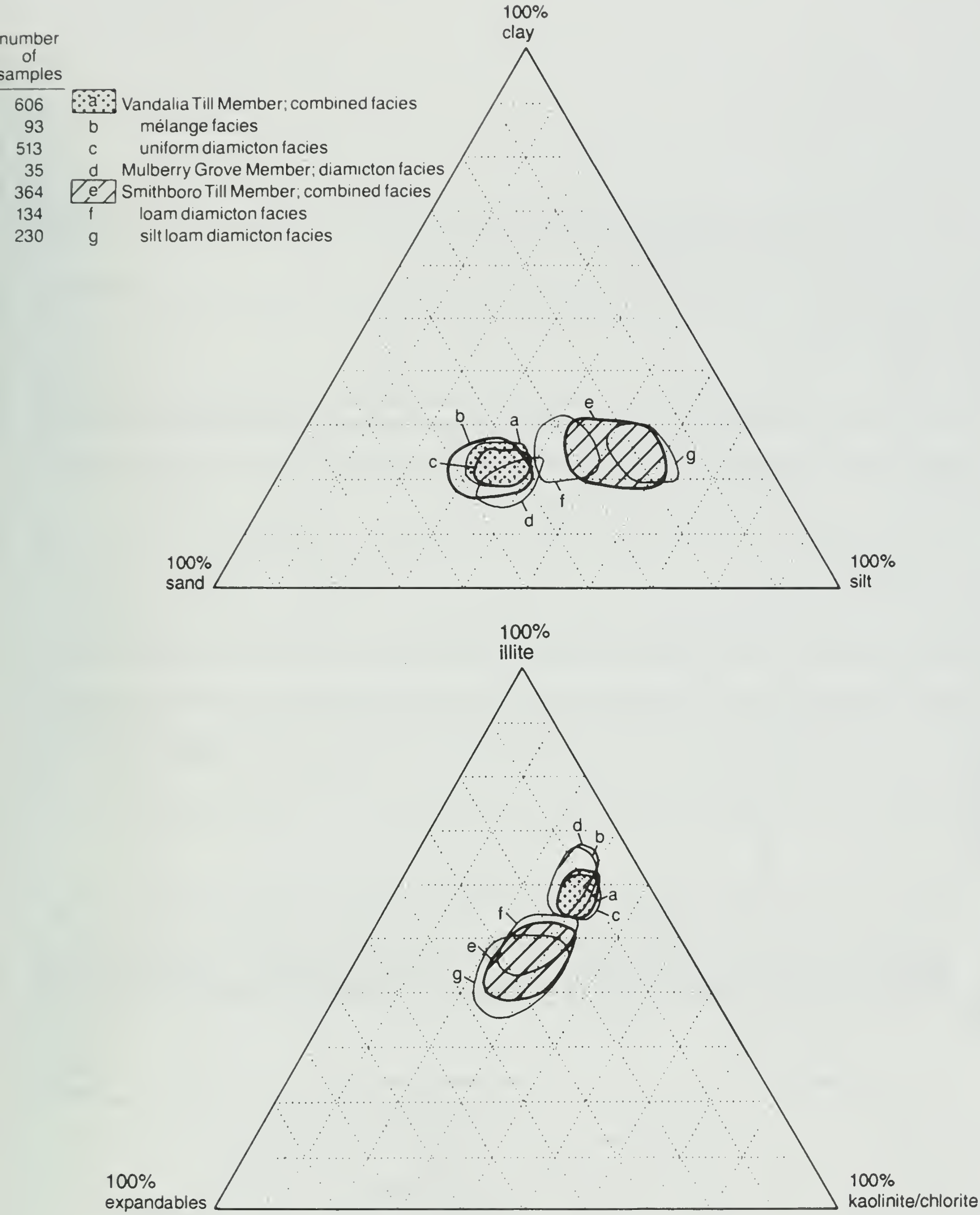
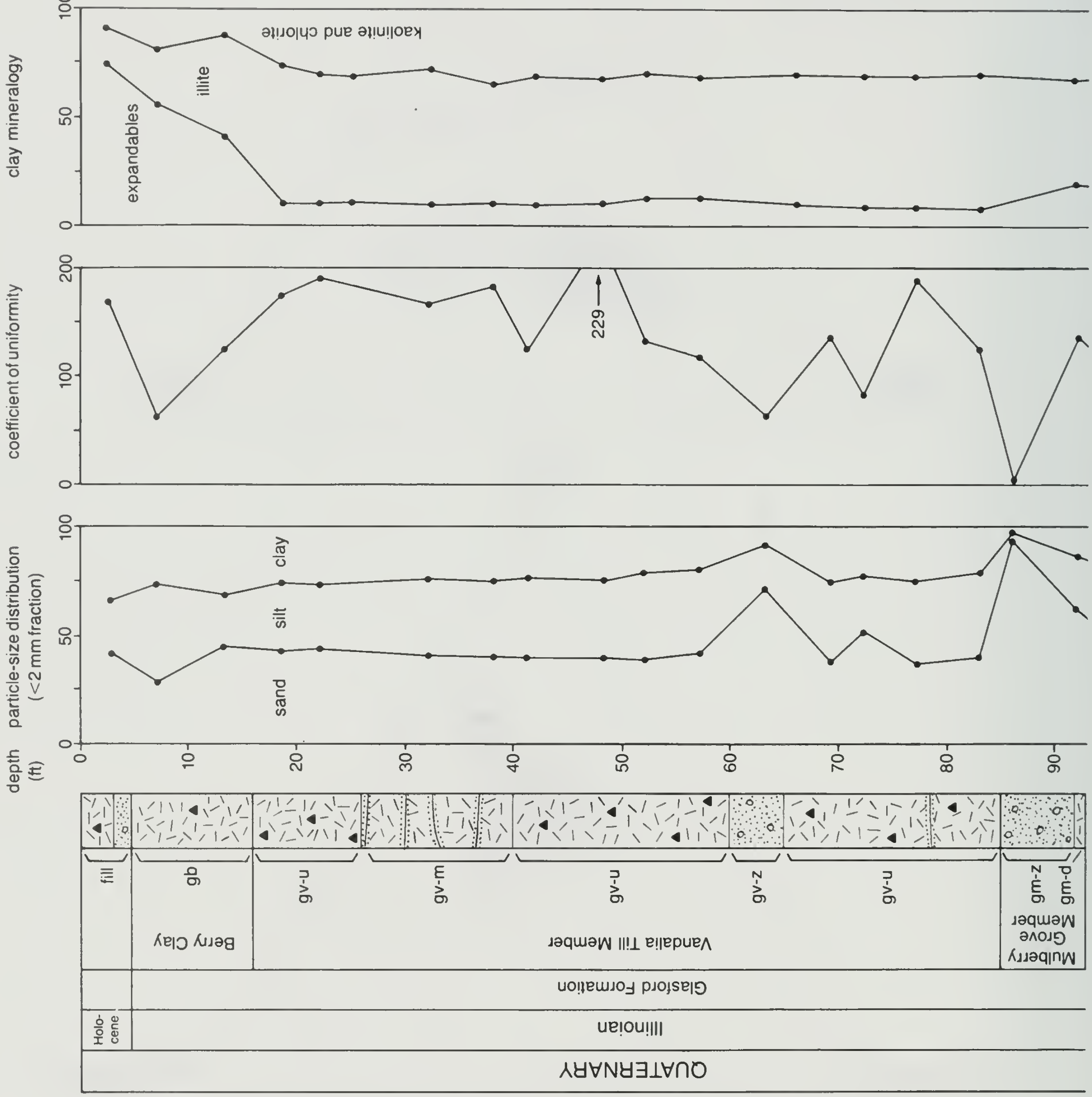


Figure 21 Ternary plots of textural and mineralogical data for diamicton units at the MAS. The envelopes encompass values within 1 standard deviation of the mean.



depth (ft)
particle-size distribution (<2 mm fraction)
sand
silt
clay
coefficient of uniformity
229
clay mineralogy
expandables
illite
kaolinite and chlorite
QUATERNARY
Holo-cene
Illinoian
Glasford Formation
fill
Berry Clay
gb
Vandalia Till Member
gv-u
gv-m
gv-z
Mulberry Grove Member
gm-z
gm-d

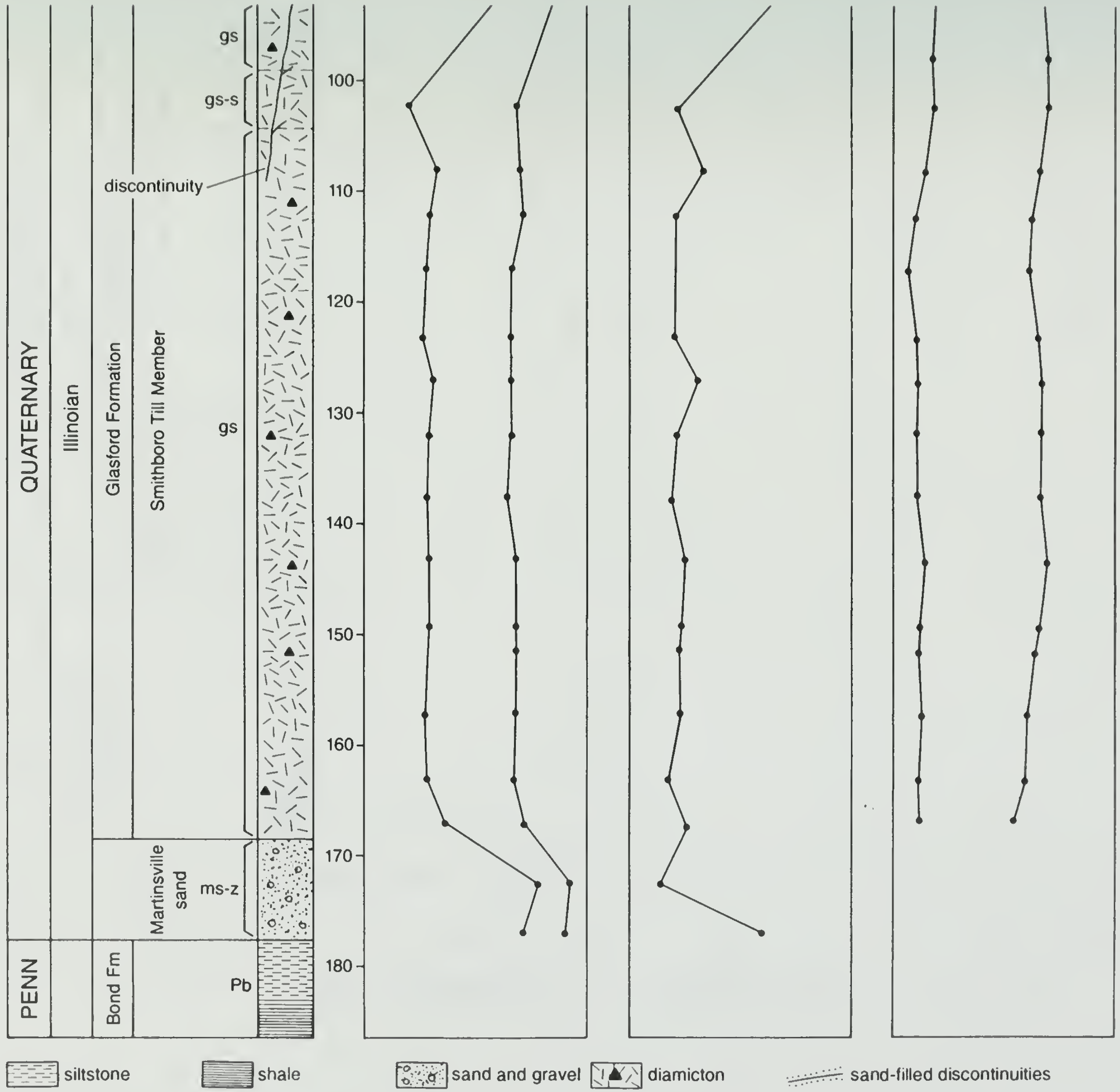
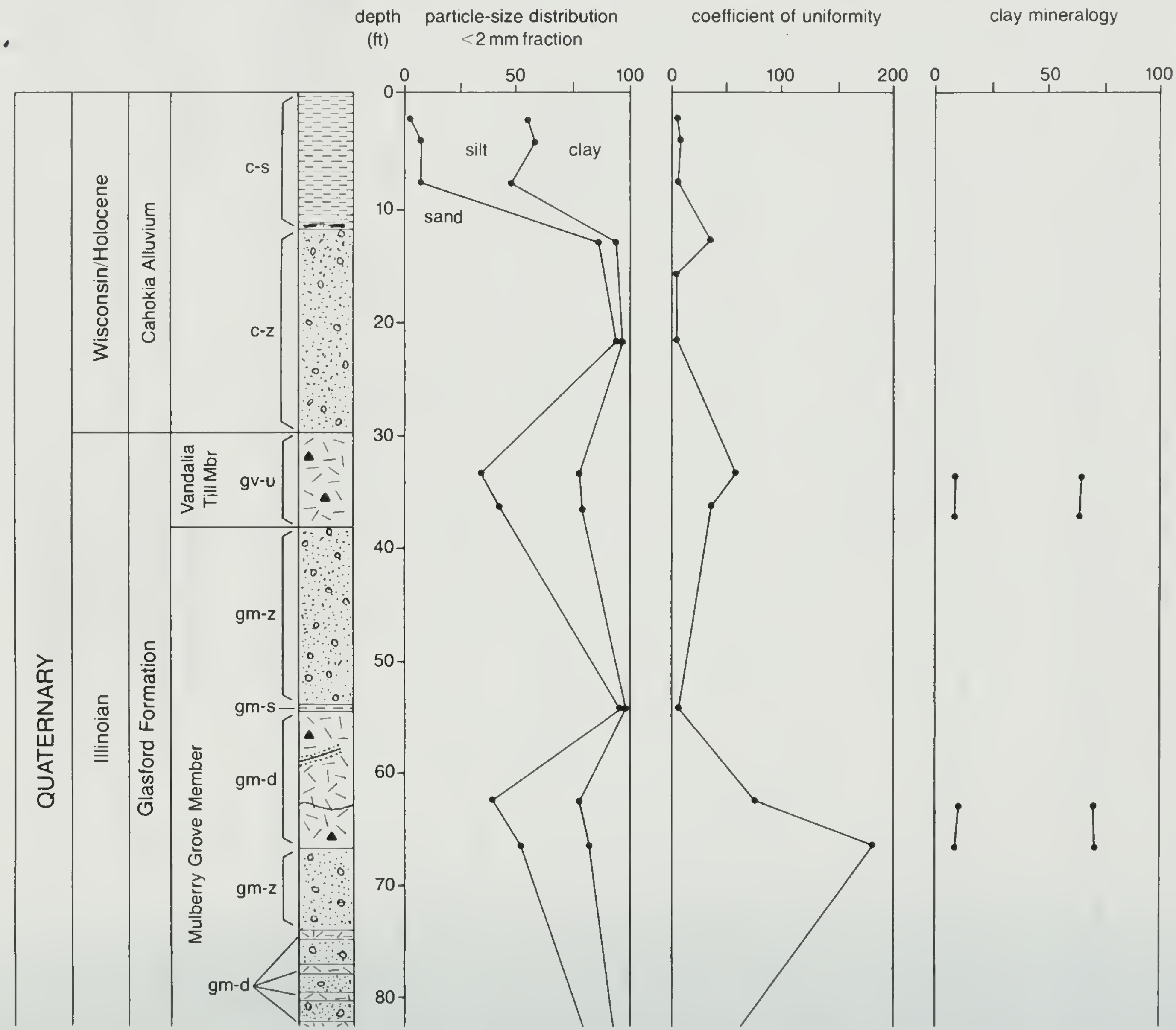


Figure 22 Lithofacies log and laboratory data from samples of core D–1. Location shown in figure 2.



depth
(ft)
particle-size distribution
<2 mm fraction
coefficient of uniformity
clay mineralogy
sand
silt
clay
QUATERNARY
Wisconsin/Holocene
Illinoian
Cahokia Alluvium
Glasford Formation
Vandalia
Till Mbr
Mulberry Grove Member
c-s
c-z
gv-u
gm-z
gm-s
gm-d
gm-z
gm-d

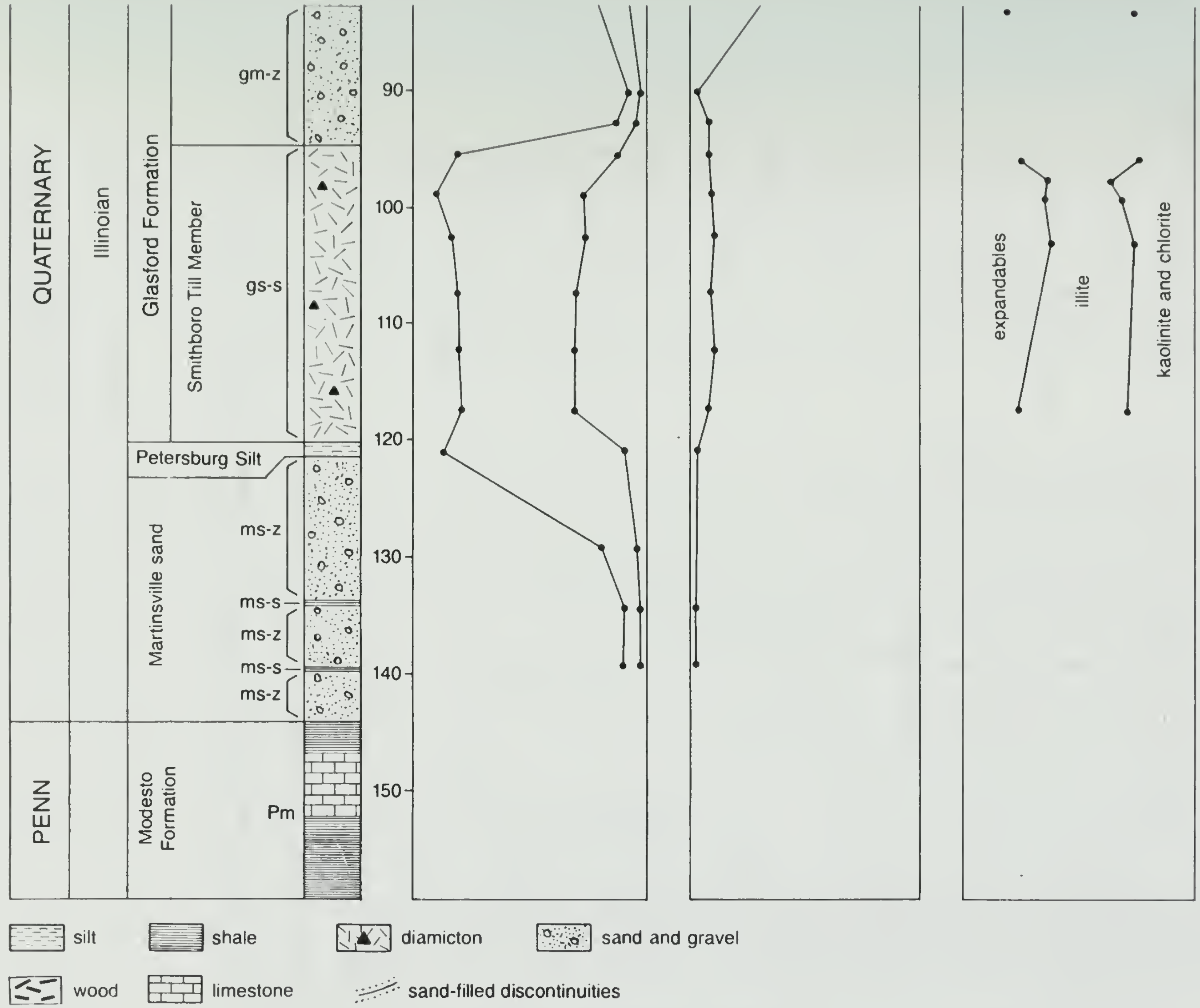


Figure 23 Lithofacies log and laboratory data from samples of core C–1. Location shown in figure 2.

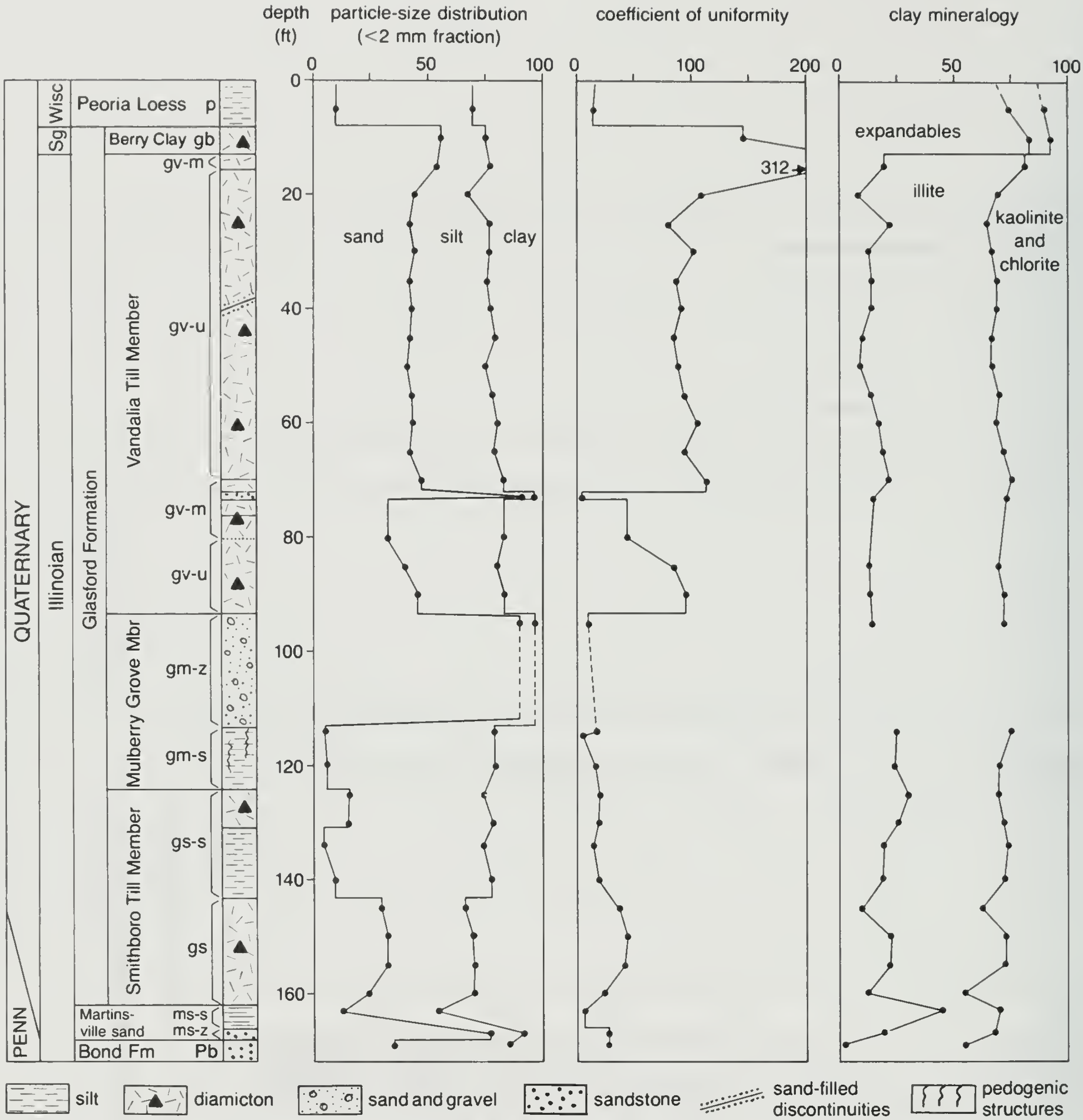


Figure 24 Lithofacies log and laboratory data from samples of core M–07. Location shown in figure 2.

Table 3 Comparison of textural and clay mineral attributes of three members of the Glasford Formation in central Illinois.

Unit Author (year of study) (No. of samples)	Percentage of the <2μm fraction Sand	 Silt	 Clay	Semiquantitative clay mineral analyses Exp*	 Illite	 K/C**
Vandalia						
Kettles (1980) (199)***	46	33	21	12	66	22
Hartline (1981) (39)	45	35	20	16	65	19
Jacobs and Lineback (1969) (10)	43	38	19	9	70	21
Lineback (1981) (97)	42	35	23	9	70	21
This study: mélange facies (86)	45	33	22	12	60	28
uniform facies (488)	43	35	22	12	58	30
Fort Russell						
Kettles (1980) (75)	35	41	24	23	57	20
Hartline (1981) (18)	40	38	22	24	56	20
Lineback (1981) (75)	32	42	26	24	54	22
Smithboro						
This study: Smithboro, loam diamicton facies (109)	32	45	23	26	47	27
Kettles (1980) (24)	26	50	24	40	41	19
Hartline (1981) (21)	23	49	28	45	37	18
Lineback (1981) (71)	25	47	28	43	38	19
This study: Smithboro, silt diamicton facies (218)	18	57	25	30	42	27
Smithboro, composite (loam diamicton and silt diamicton combined) (327)	23	53	24	29	44	27

* Exp = expandable clay minerals; ** K/C = kaolinite plus chlorite; *** composite of Kettle's Till 50W and Till 50E

Figure 25 Lithofacies log and laboratory data from samples of core M–106. Location shown in figure 2.

at boring M–07, where it is composed of both leached and calcareous intervals of organic-bearing silt that contains abundant root traces (fig. 24). The weakly developed soil profiles are tentatively correlated with the Pike Soil.

Pike Soil

Willman and Frye (1970) named the Pike Soil in western Illinois for a strongly developed, weathering profile in the Kellerville Till Member of the Glasford Formation. Correlation of the Smithboro and Kellerville Till Members (Lineback 1979b) indicates that the paleosol developed in the Mulberry Grove Member at the MAS is the Pike Soil. The Pike Soil in western Illinois is of interglacial character (Lineback 1979b, Johnson 1986), whereas the soil of the Pike in eastern Illinois is of interstadial character (Johnson, Gross, Moran 1971). The difference in the degree of weathering suggests that the temporal correlation of the Smithboro and Kellerville Till Members may not be valid, but current evidence supports the tentative stratigraphic assignment of the Pike in eastern Illinois.

Vandalia Till Member

The Vandalia Till Member of the Glasford Formation, the thickest and most widespread till unit in central Illinois, has been mapped and described in several reports (Johnson 1964, Jacobs and Lineback 1969, Johnson et al. 1972, McKay 1979, Lineback 1979a, b, Follmer et al. 1979, Kettles 1980, Hartline 1981, Follmer 1982, Fox 1987, Battelle Memorial Institute and Hanson Engineers, Inc. 1990a, b). The Vandalia Till Member consists of loam diamicton that regionally has a distinct particle-size distribution and clay mineralogy (table 3). In this study, the means and standard deviations of the sand–silt–clay contents for Vandalia diamicton are 42.7 ± 5.4% sand, 34.8 ± 5.4% silt, and 22.3 ± 3.8% clay; the means and standard deviations for clay minerals are 12.4 ± 4.5% expandables, 57.8 ± 4.8% illite, and 29.6 ± 3.4% kaolinite plus chlorite (appendix). The mineralogy of the fine sand fraction indicates that the Vandalia was deposited by the Lake Michigan Lobe of the Laurentide Ice Sheet (Johnson 1964, Fox 1987). The mean coefficient of uniformity of particle-size distribution for Vandalia Till at the MAS is much greater than that of the underlying Smithboro (106 vs. 32, all facies combined; fig. 29; appendix), a discrepancy indicating that the Vandalia is less sorted than the Smithboro. The texture and sorting coefficients of the lower 10 to 15 feet of the Vandalia Till are, however, similar to the loam diamicton facies of the Smithboro Till Member. Small differences in clay mineralogy, outlined below, are useful in differentiating between the Vandalia and Smithboro where the Mulberry Grove is thin or absent. The following characteristics aid in differentiating Vandalia and Smithboro diamictons in the contact zone.

(1) The lower Vandalia and the diamicton facies of the Mulberry Grove commonly contain more illite than the loam diamicton facies of the Smithboro (mean values of about 60% and 47%, respectively; fig. 21).

(2) The basal Vandalia diamicton and the diamicton facies of the Mulberry Grove commonly have vermiculite indices less than 0. The loam diamicton facies of the Smithboro has values greater than 1.

(3) The Vandalia generally has coefficients of uniformity greater than 50; Smithboro has coefficients less than 50 (fig. 29).

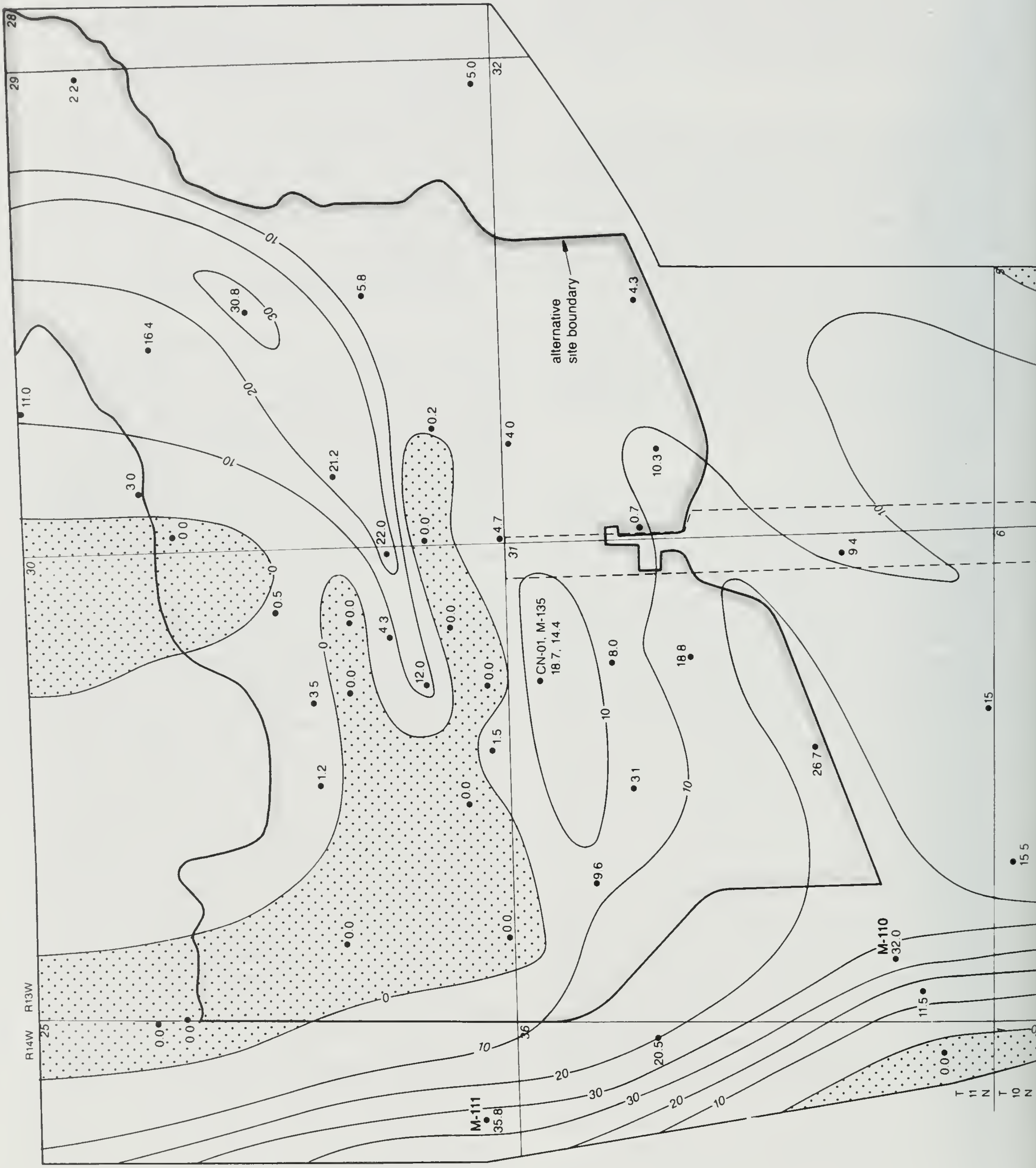
(4) X-ray diffractograms of unoxidized Vandalia rarely have diffraction peaks discernible from background at the 5.1° 2θ (17Å) position, which results in no measurement of the heterogeneous swelling index (HSI; ISGS 1989). The opposite generally is the case with the Smithboro, and the HSI is greater than or equal to 0 (fig. 30).

(5) The Vandalia generally contains more sand (mean 42.7%) than the Smithboro (mean 23.1%; appendix).

Two facies of the Vandalia Till Member are recognized at the MAS: a lower, uniform diamicton facies and an upper, mélange facies. The diamicton of both facies has similar texture and mineralogy (fig. 21). In Battelle Memorial Institute and Hanson Engineers, Inc. (1990a, b, c), the uniform diamicton facies is named the Vandalia Till, and the mélange facies is named the Fractured Vandalia Till (table 2). In a few locations, the mélange facies occurs at or near the base of the uniform diamicton facies (fig. 24). In such cases, the mélange facies correlates with the Vandalia Till of Battelle.

Uniform diamicton facies The uniform diamicton facies (gv–u in table 1), as much as 129.4 feet thick at boring M–112, is known to be absent only at the mouth of Bluegrass Creek adjacent to the MAS (fig. 31). The uniform diamicton facies elsewhere in the study area is at least 40 feet thick beneath the uplands (e.g., fig. 3) and generally less than 15 feet thick beneath the valley of the North Fork Embarras River (fig. 14). The uniform diamicton facies, composed of loam diamicton, is characteristically massive; however, discontinuities are spaced more than 3 feet apart (Battelle Memorial Institute and Hanson Engineers, Inc. 1990a). The types of discontinuities include joints or fractures and lithologic discontinuities between diamicton and granular material. When partly dried, the core commonly breaks with difficulty along nearly horizontal partings that commonly have a thin, discontinuous filling composed of sand or silt. The uniform diamicton facies was not observed in outcrops in the study area.

Sand and gravel layers, locally as much as 18.5 feet thick at M–10, are present in the uniform diamicton facies at the MAS. Limited information from borings suggests that the sand and gravel occurs in channels, but the width and length of the channels are unknown. A sand and gravel deposit that appears to have limited lateral continuity within the uniform diamicton facies at the MAS is referred to as Vandalia Sand by Battelle Memorial Institute and Hanson Engineers, Inc. (1990a, b, c; table 2 in this report). The Vandalia Sand appears to be, on the basis of head data from piezometers, hydraulically discontinuous across the MAS. In parts


alternative
site boundary
CN-01, M-135
18.7, 14.4
M-110
32.0
M-111
35.8
R14W
R13W
T 11 N
T 10 N

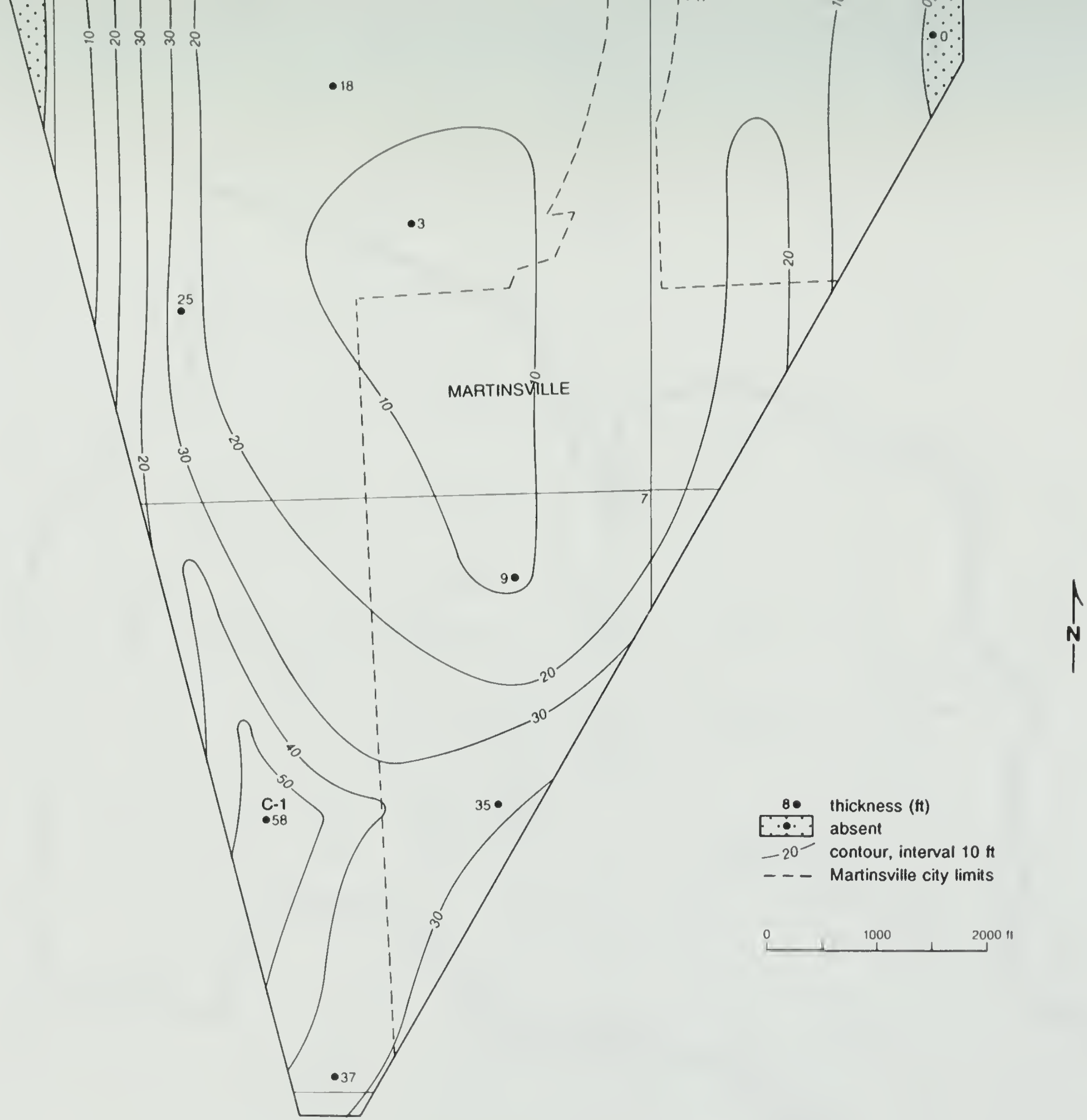
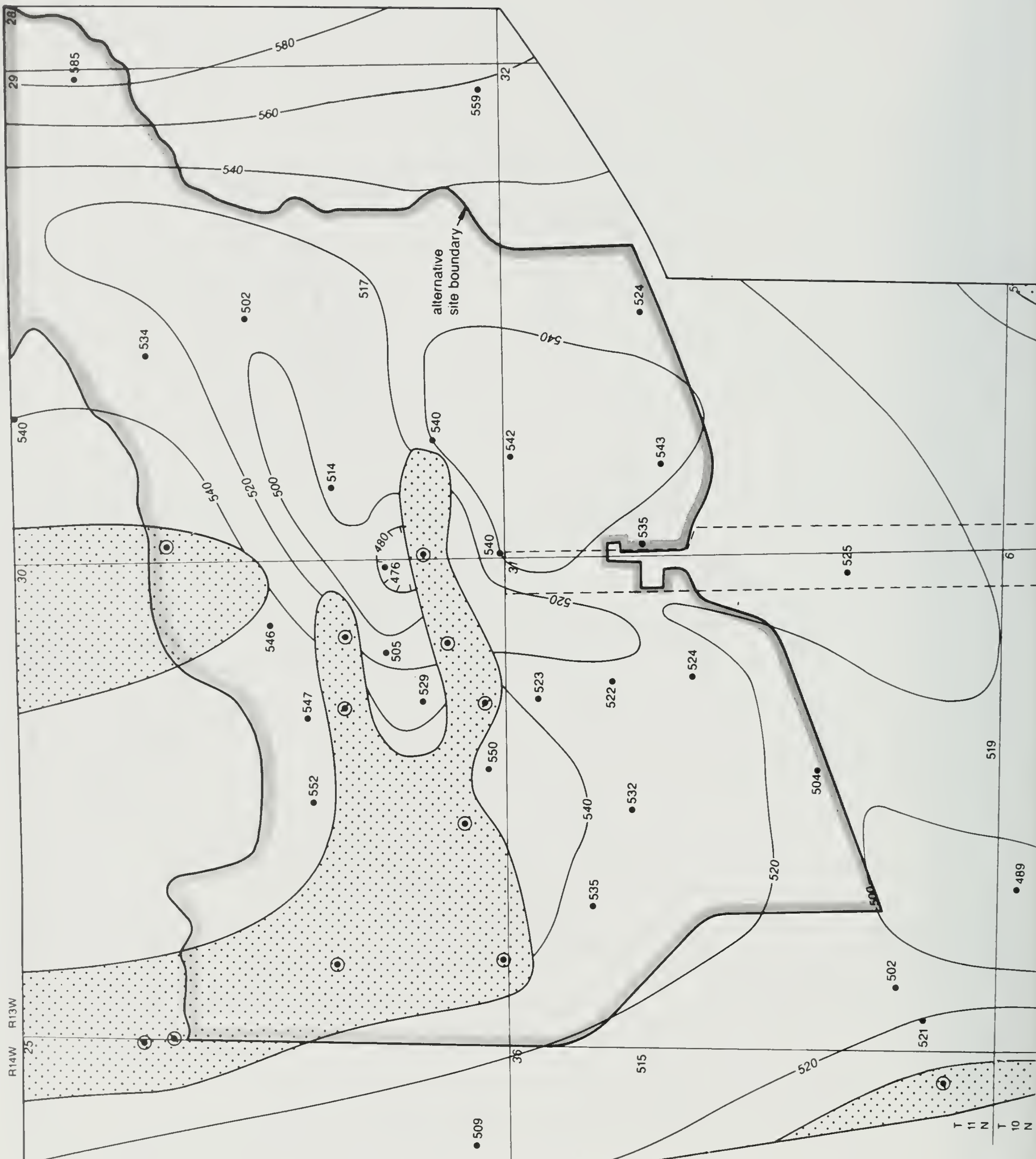


Figure 26 Thickness of the Mulberry Grove Member, Glasford Formation.



alternative
site boundary
580
560
540
517
520
500
480
476
28
29
30
32
31
36
25
6
5
R14W
R13W
T 11 N
T 10 N
585
559
534
502
524
540
542
543
514
535
525
546
505
529
523
522
524
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489
502
521
515
509

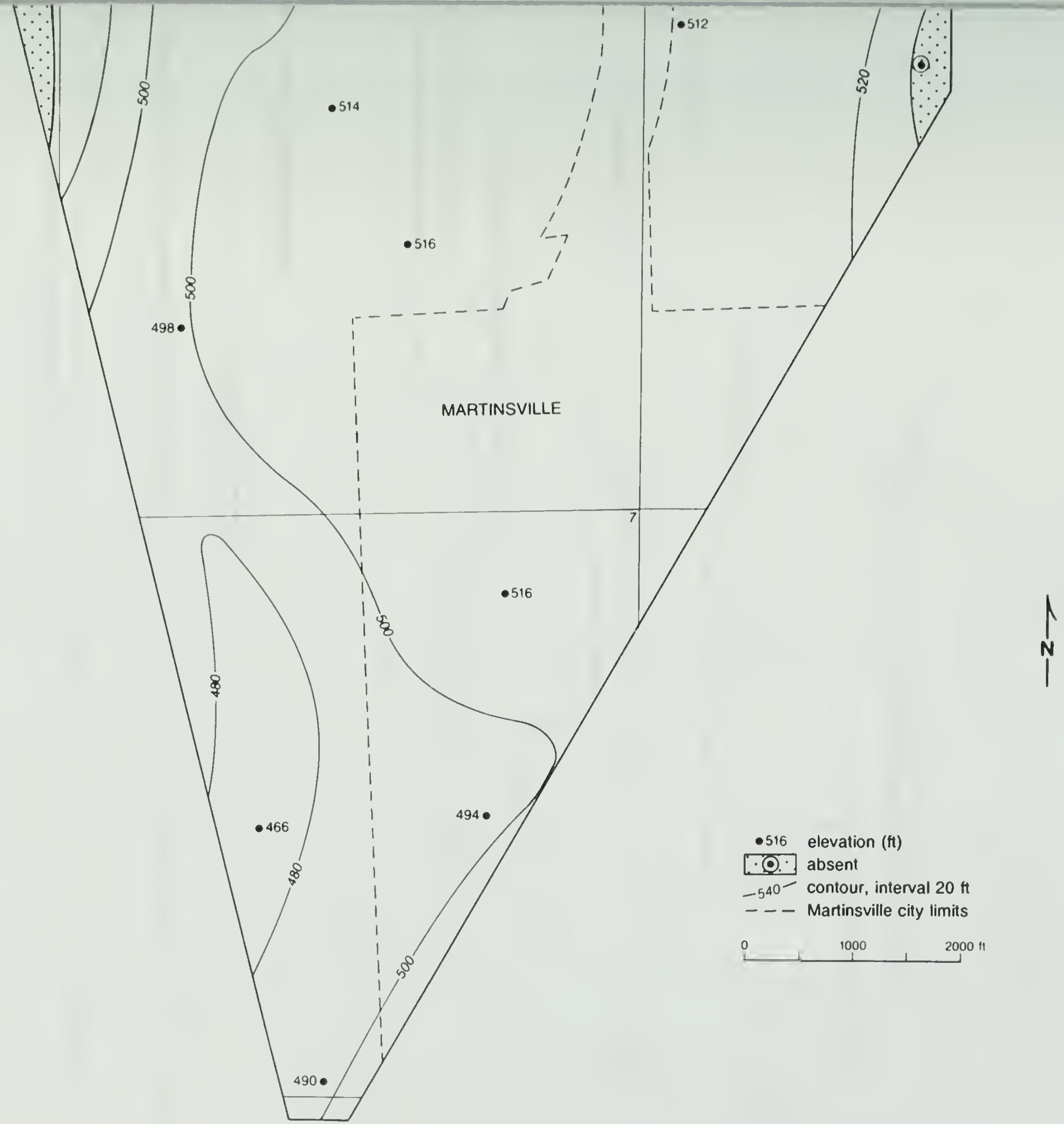
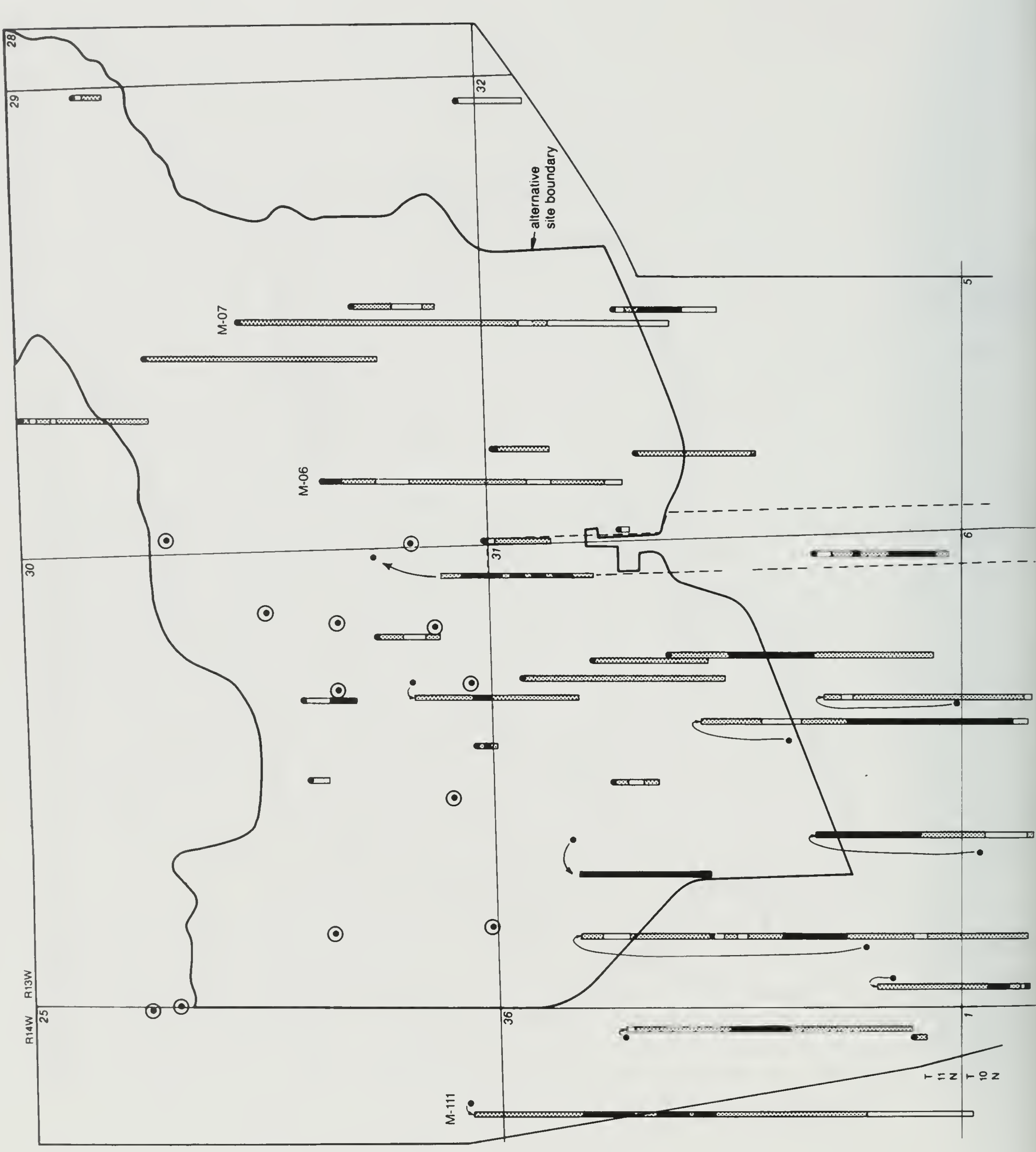


Figure 27 Elevation of the lower surface of the Mulberry Grove Member, Glasford Formation.



28
29
32
alternative site boundary
5
M-07
M-06
30
31
6
R14W
R13W
25
36
1
T 11 N
T 10 N
M-111

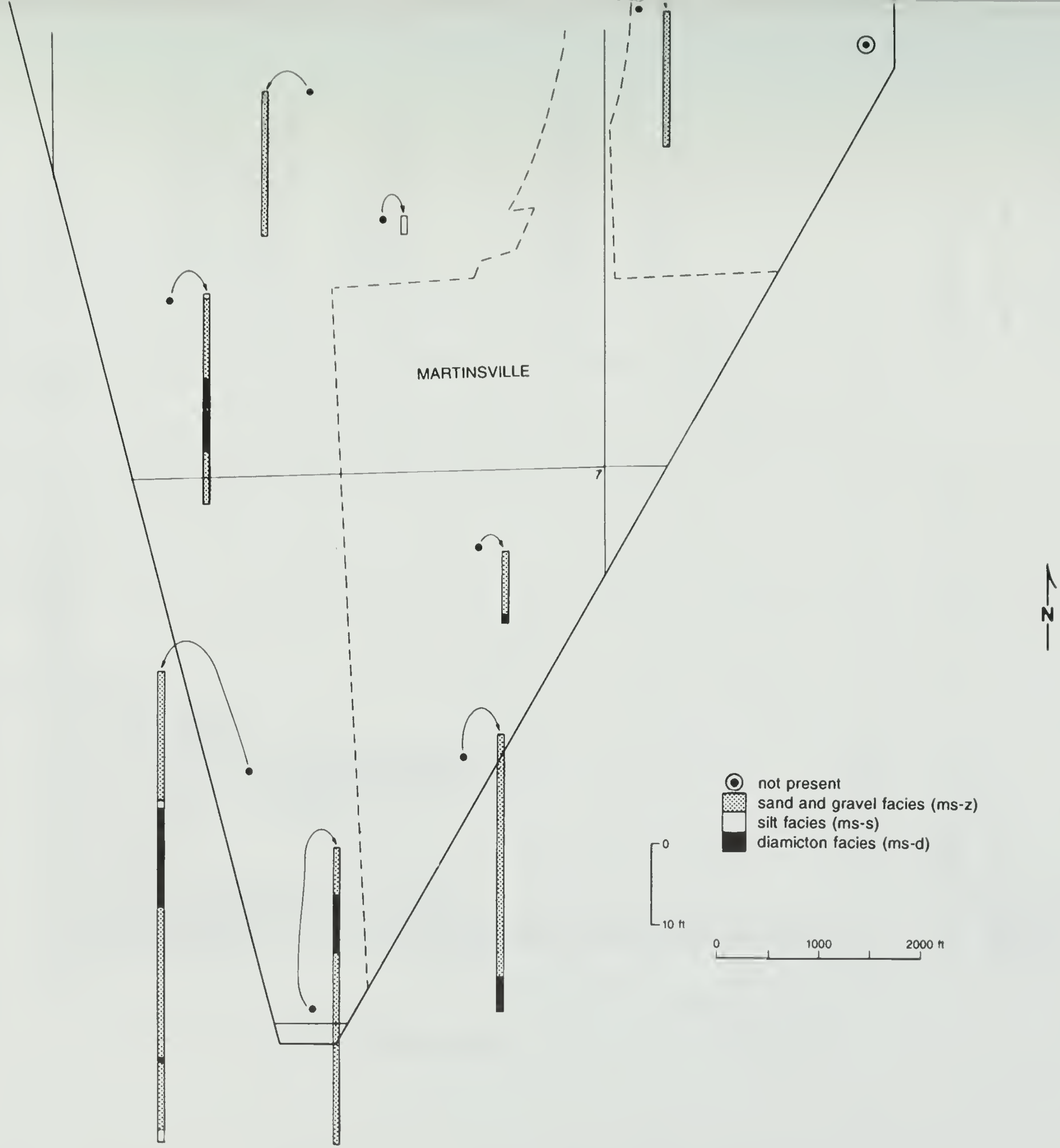


Figure 28 Thickness of lithofacies of the Mulberry Grove Member.

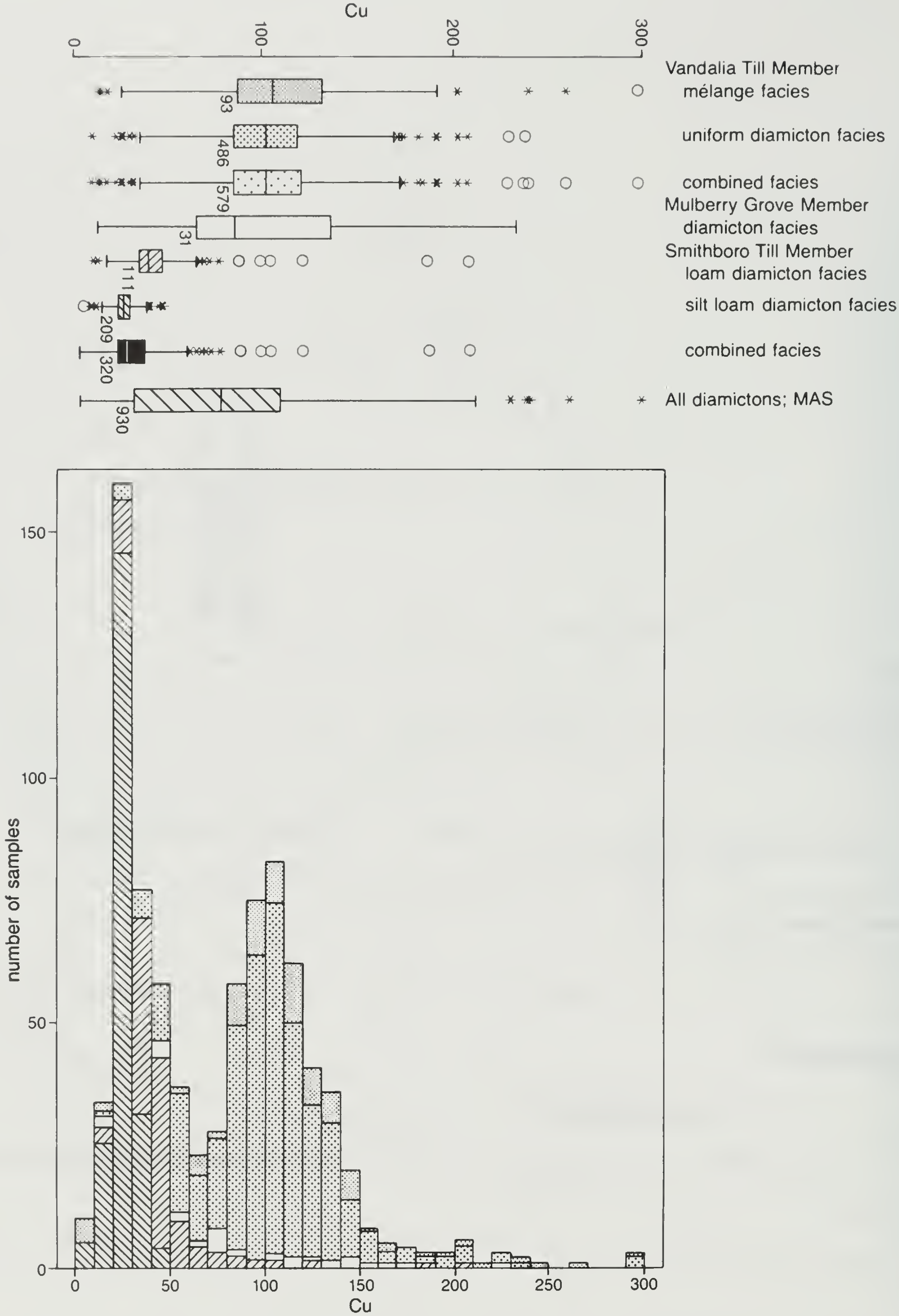


Figure 29 Histogram and box diagrams of values of the coefficient of uniformity (Cu) for glacigenic diamicton units at the MAS. Within the boxes of the box diagrams, the range of values falls within 1 interquartile range about the median, which is shown as a line within the box. The lines extending from the boxes (the "whiskers") are 1.5 times the value of the interquartile range beyond the range indicated by the box; outside values (shown as asterisks) found beyond the "whiskers" are as much as 3.0 times the interquartile range; extreme outside values (shown as open circles) are more than 3.0 times the interquartile range (see Velleman and Hoaglin 1981).

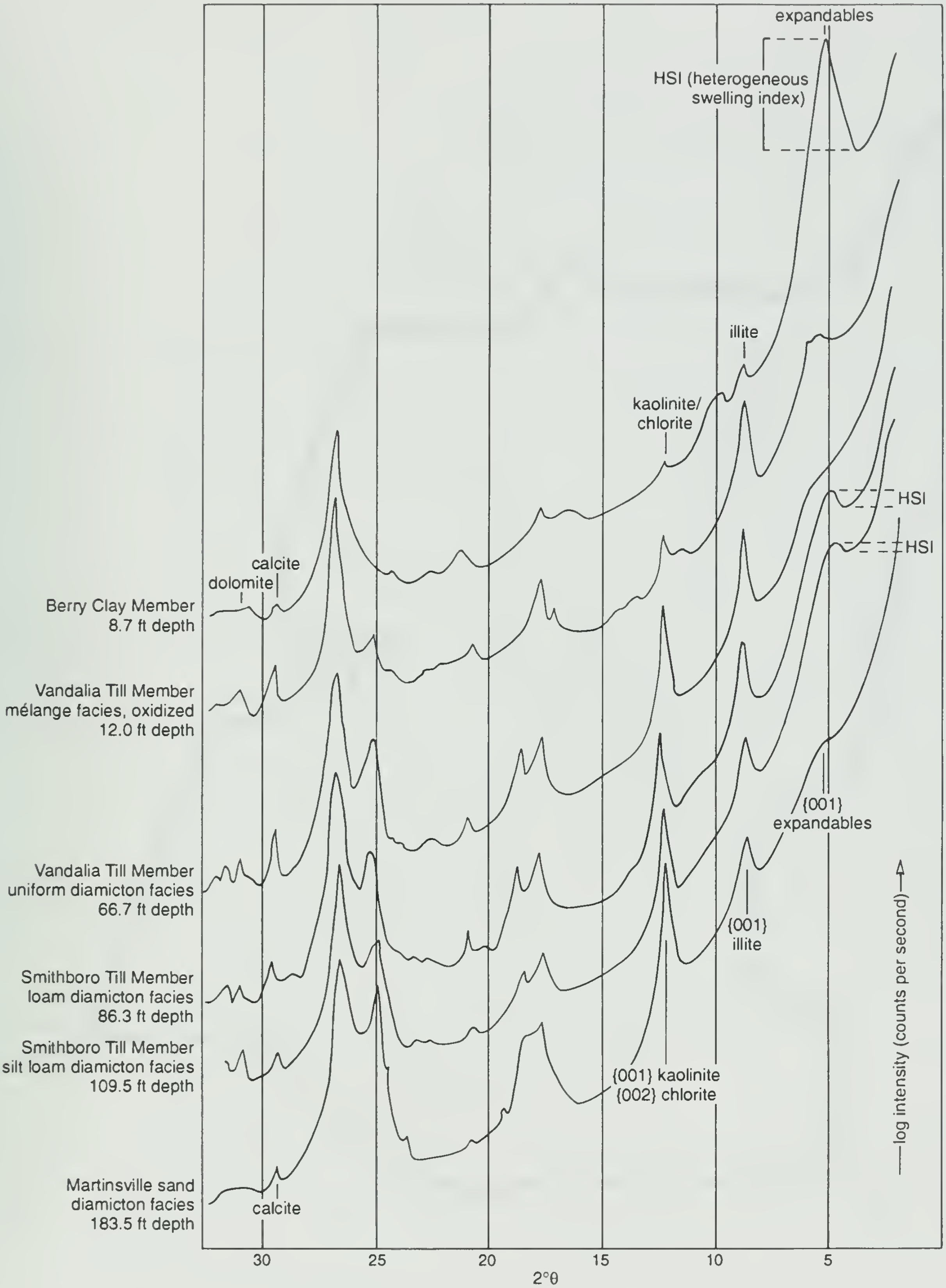


Figure 30 Smoothed traces of X-ray diffractograms of oriented, ethylene glycol solvated samples of the <2 μm fraction of units from boring M–104.

alternative site boundary
M-112
129.4
114.0
89.4
75.4
65.0
56.3
53.9
59.3
71.5
55.0
59.4
41.5
34.6
49.0
58.0
32.5
37.6
48.1
64.8
50.6
54.0
39.0
50.0
55.8
69.0
52.5
54.5
64.5
51.0
55.0
53.0
46.0
66.3
58.7
48.0
8.3
5.2
15.5
13.7
10.0
0.0
12.0
120
100
80
60
40
20
0
28
29
32
30
31
36
25
5
6
1
R14W
R13W
T 11 N
T 10 N

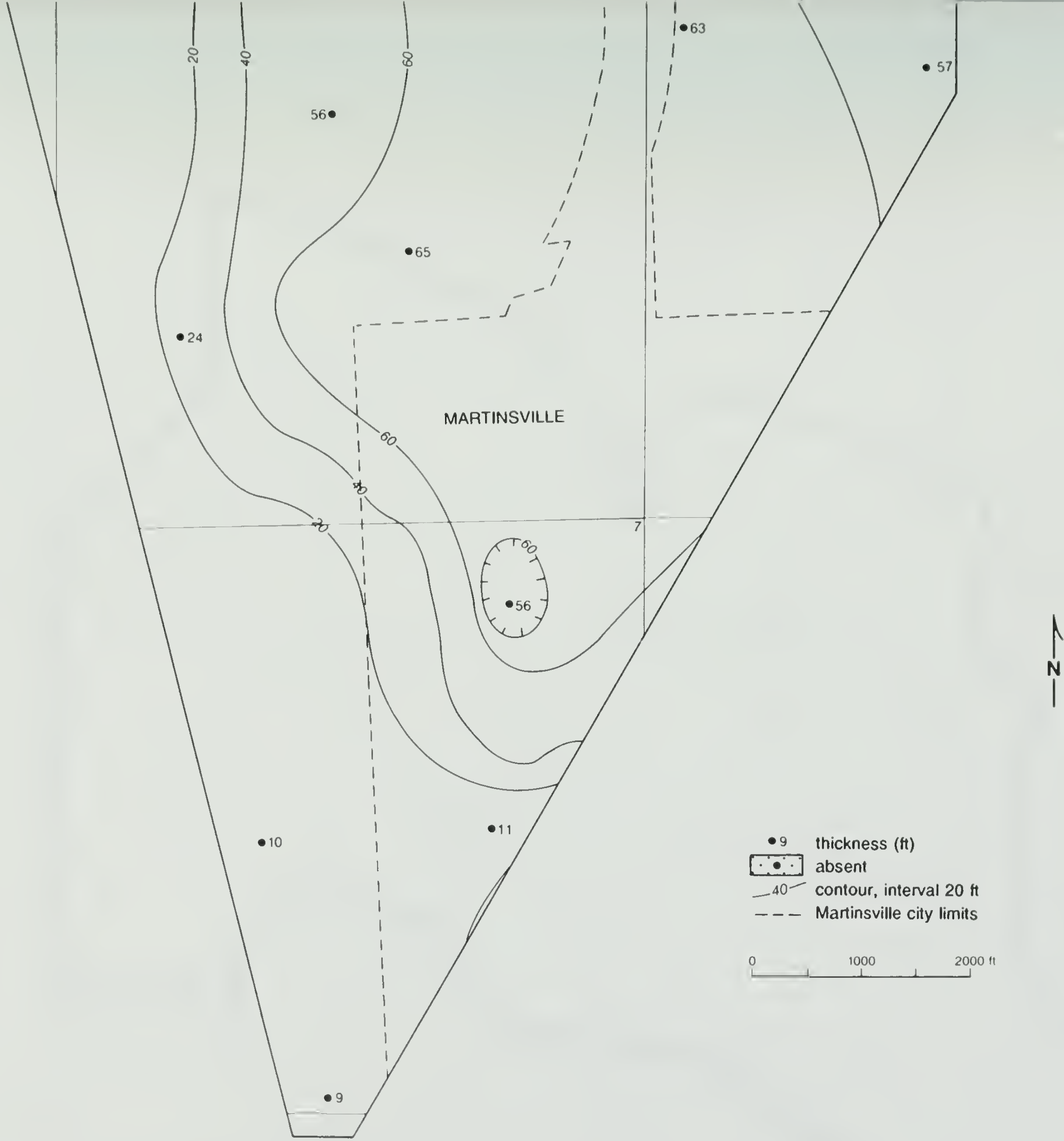
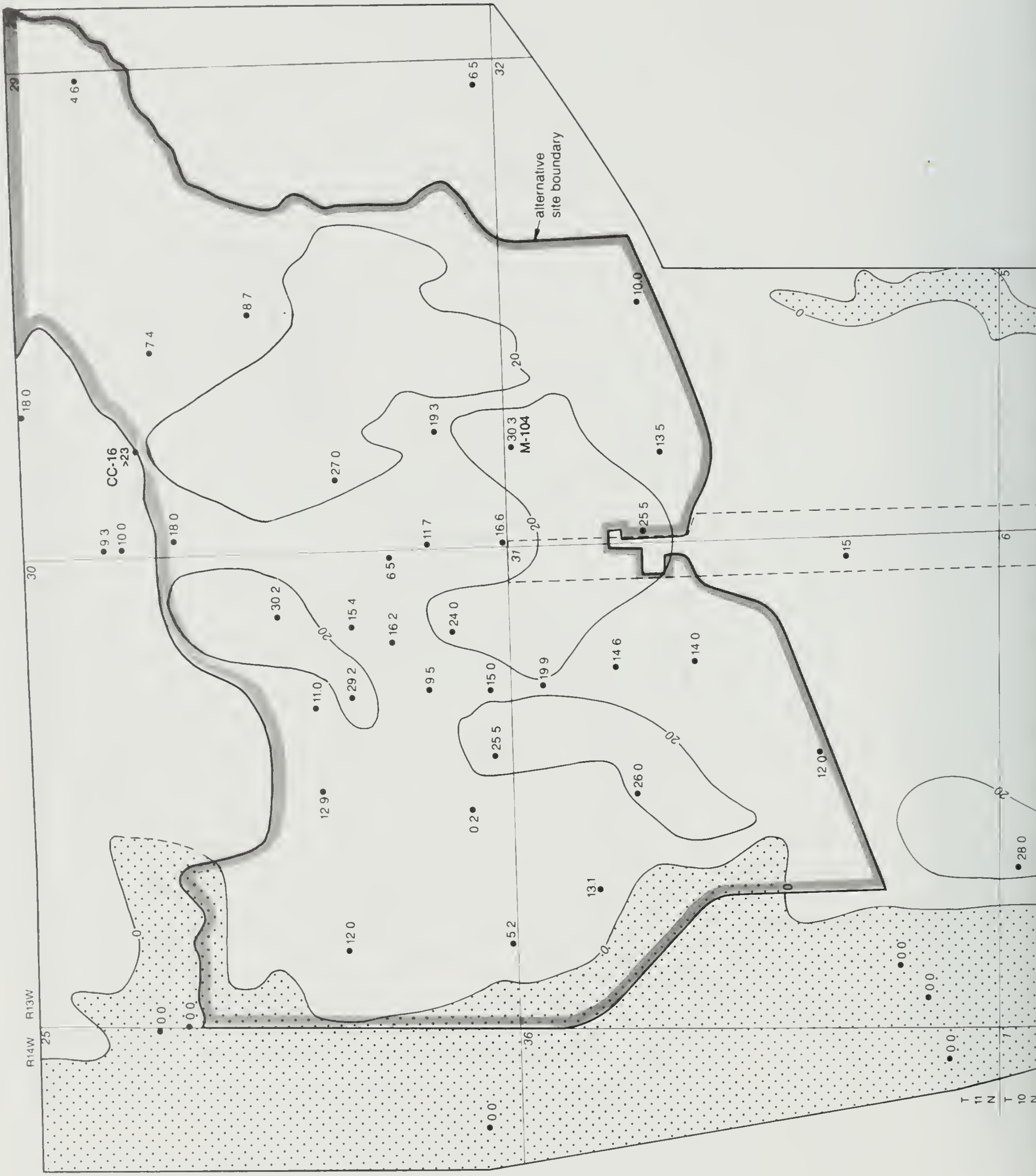


Figure 31 Thickness of the uniform diamicton facies of the Vandalia Till Member, Glasford Formation.


alternative site boundary
CC-16
>23
M-104
R14W
R13W
T 11 N
T 10 N

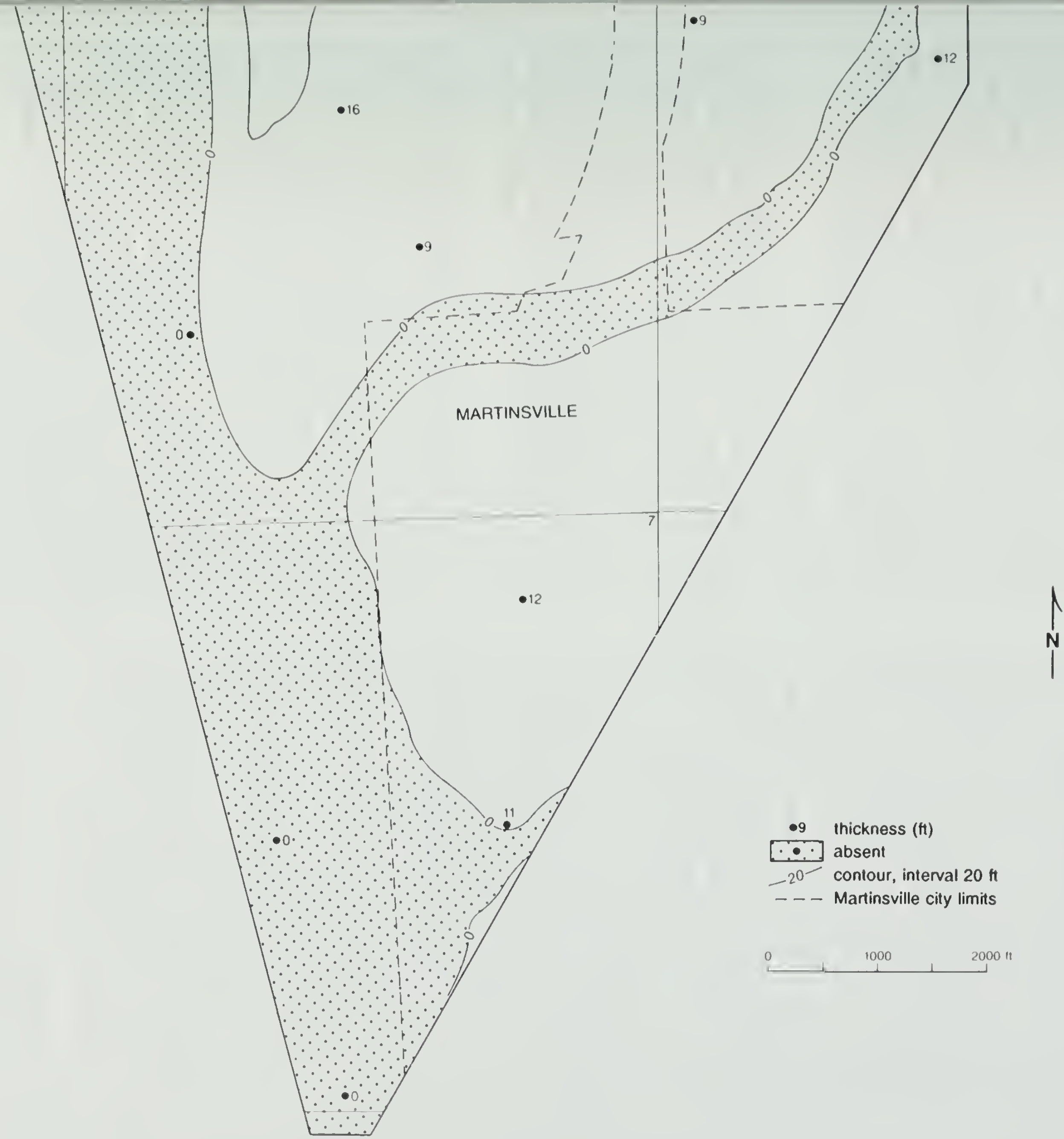


Figure 32 Thickness of the mélange facies of the Vandalia Till Member, Glasford Formation.

of the site, the Vandalia Sand has heads similar to those of the Mulberry Grove; in other parts, head data are similar to those of the surficial layers and the mélange facies.

Mélange facies The mélange facies (gv-m in table 1) is composed predominantly of loam diamicton, but numerous layers, lenses, and pods of sand and gravel, and less commonly, well sorted, uniform silt also are present. Contacts between sand and gravel bodies, diamicton, and silt are sharp. The mélange facies contains at least one lithologic or structural discontinuity per vertical or horizontal 3 feet of sediment. The mélange facies is more than 23 feet thick in an outcrop (CC–16) adjacent to the MAS, and as much as 30.3 feet thick beneath the MAS at boring M–104 (fig. 32). Below the uplands, the mélange facies is generally found at the top of the Vandalia but, in rare instances, it occurs at depth within the uniform diamicton facies (for example, at a depth of 73–80 ft in boring M–07; fig. 24). The facies generally is absent beneath the valley of the North Fork Embarras River.

The mélange facies contains numerous discontinuities with variable orientation and habit, including lithologic discontinuities and fractures. At outcrop CC–15, there are nearly vertical joints at least 10 feet long and filled with sand. These joints have a maximum width of 1 inch and taper downward to a crack with no sand filling (fig. 33a). At the same outcrop, vertically oriented tabular beds of uniform silt are offset along glaciotectonic faults with about 2 feet of apparent displacement. At outcrop CC–16, the grain of the lithologic discontinuities is generally horizontal with planar to wavy surfaces (fig. 33b). Observations of outcrops and unoriented core from four clusters of angled borings indicate that the discontinuities occur in all dip orientations. The angled borings also indicate that the contact between the uniform diamicton facies and mélange facies is abrupt. The cluster of angled borings at M–101 illustrates the slope of the contact surface. The slope is as much as 14° within a horizontal distance of about 50 feet (fig. 34).

Observations of outcrops and core from vertical and angled borings provide an indication of the variability and complexity of the distribution of fractures and sand lenses within the mélange facies (figs. 33a, b, 34, 45, 46). Scattered sand lenses, ranging from less than 1 inch to as much as 10 feet thick, were observed in cores and outcrops. The proportion of sand as lenses, bodies, and fracture fillings in the mélange facies ranges from less than 1% to 70%, and averages 15%.

Berry Clay Member

The Berry Clay Member is composed of leached and pedogenically modified loam to clay loam diamicton. Beneath the upland surfaces at the MAS, the Berry forms a continuous layer over the Vandalia Till Member of the Glasford Formation and under the sandy silt facies of the Roxana Silt. In this report, the Berry Clay Member is included in the upper Pearl Formation (peb in table 1) to emphasize the continuity of this mantle. Average thickness of the Berry Clay is 5 feet; maximum thickness is 13 feet.

The Berry Clay Member contains more expandable clay minerals than underlying units (fig. 35, appendix), although the lowermost portion commonly has a clay mineral composition similar to that of oxidized Vandalia diamicton. Mean values for clay mineral content are 59% expandables, 27% illite, and 14% kaolinite plus chlorite. Where the Pearl sand is absent, the contact between the Berry and the Vandalia generally is abrupt, and pedogenically the contact is at the boundary between the B and C horizons of the Sangamon Soil. Visually, the Berry Clay can be difficult to differentiate from the overlying Roxana Silt, which contains little or no gravel and possesses finer pedogenic features than the Berry. The contact between the Berry and the Roxana generally is gradational across a 1 foot zone. Although textural differences are useful for differentiating the surficial upland units, clay mineralogy is not a useful differentiating method (fig. 36).

Pearl Formation

The Pearl Formation discontinuously overlies the mélange facies of the Vandalia Till Member of the Glasford Formation. The Berry Clay Member is the soft, gleyed diamicton in the upper Pearl. Pearl sand, referred to as the Upper Sand by Battelle Memorial Institute and Hanson Engineers, Inc. (1990a; table 2 in this report), was not observed in the sediment fill of present-day valleys. The mean thickness of the Pearl at the MAS is 1.9 feet; a maximum thickness of 12.9 feet occurs in angled boring M–106W adjacent to boring M–106 (Battelle Memorial Institute and Hanson Engineers, Inc. 1990a).

The Pearl Formation is composed of stratified, poorly sorted sand and gravel; well sorted, medium grained sand; and uncommon, thin interbeds of silty clay. Illuvial clay occurs in the upper portion of the Pearl and is related to the Sangamon Soil. Its pedogenic origin is indicated by an abundance of fine clay (<1 µm) relative to coarser clay (1–4 µm; fig. 35). Pearl Formation particles commonly are stained and coated with sesquioxides and clay that demarcate gamma horizons (layers of translocated clay, organic matter, and sesquioxides below primary and beta B horizons; Johnson and Hansel 1989). Clay mineralogy of the Pearl Formation is similar to that of the uppermost weathered Vandalia diamicton. Mean clay mineral values are 37% expandables, 48% illite, and 15% kaolinite plus chlorite (appendix). The lower contact of the Pearl at outcrop CC–16 is locally convoluted, above which are stratified and undeformed beds of sand or silty clay, completely stained black and red by sesquioxides.

Sangamon Soil

The B horizon of the Sangamon Soil commonly occurs in the Berry Clay Member of the Glasford and Pearl Formations and the upper 1 to 2 feet of the mélange facies of the Vandalia Till Member. The latter material

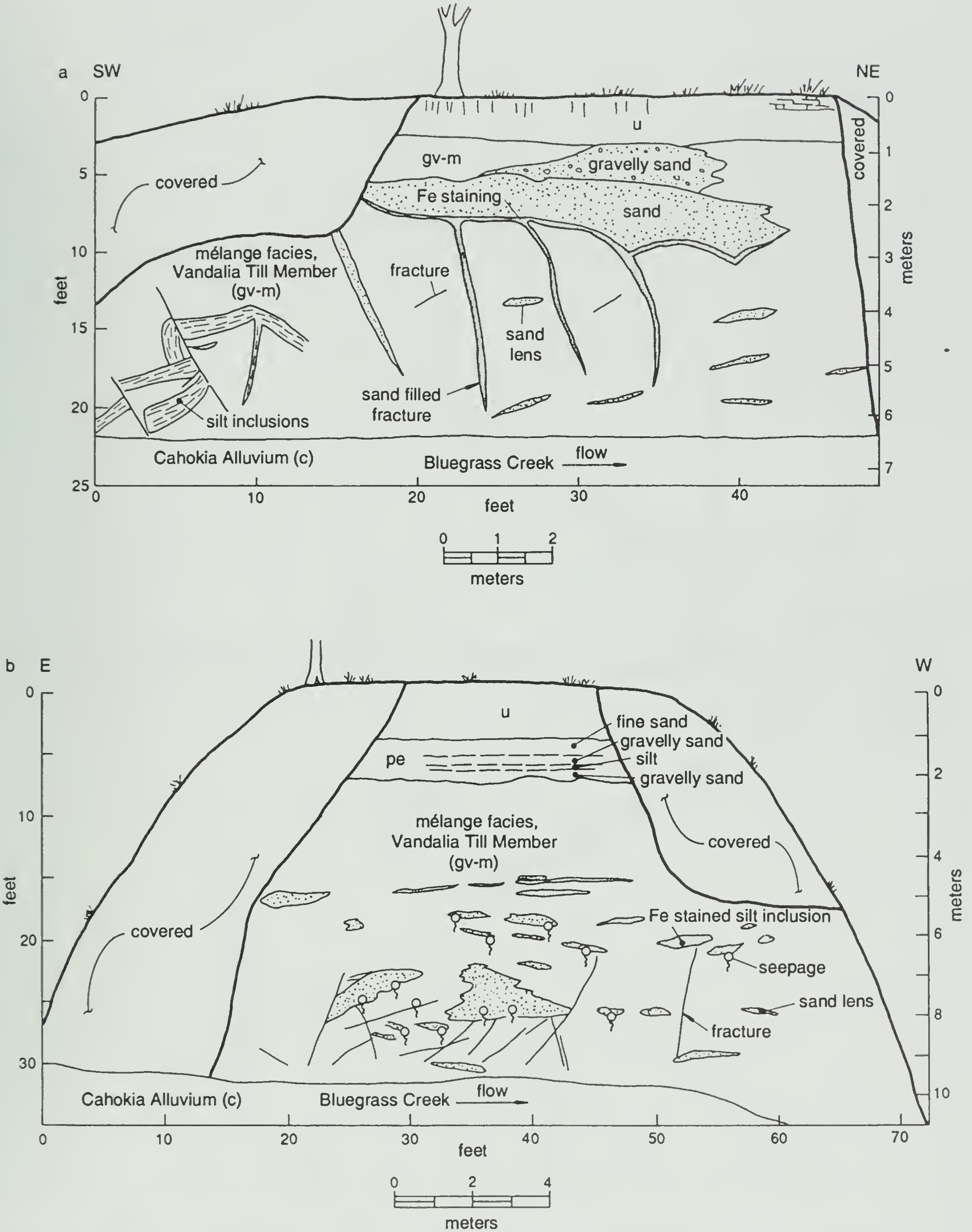
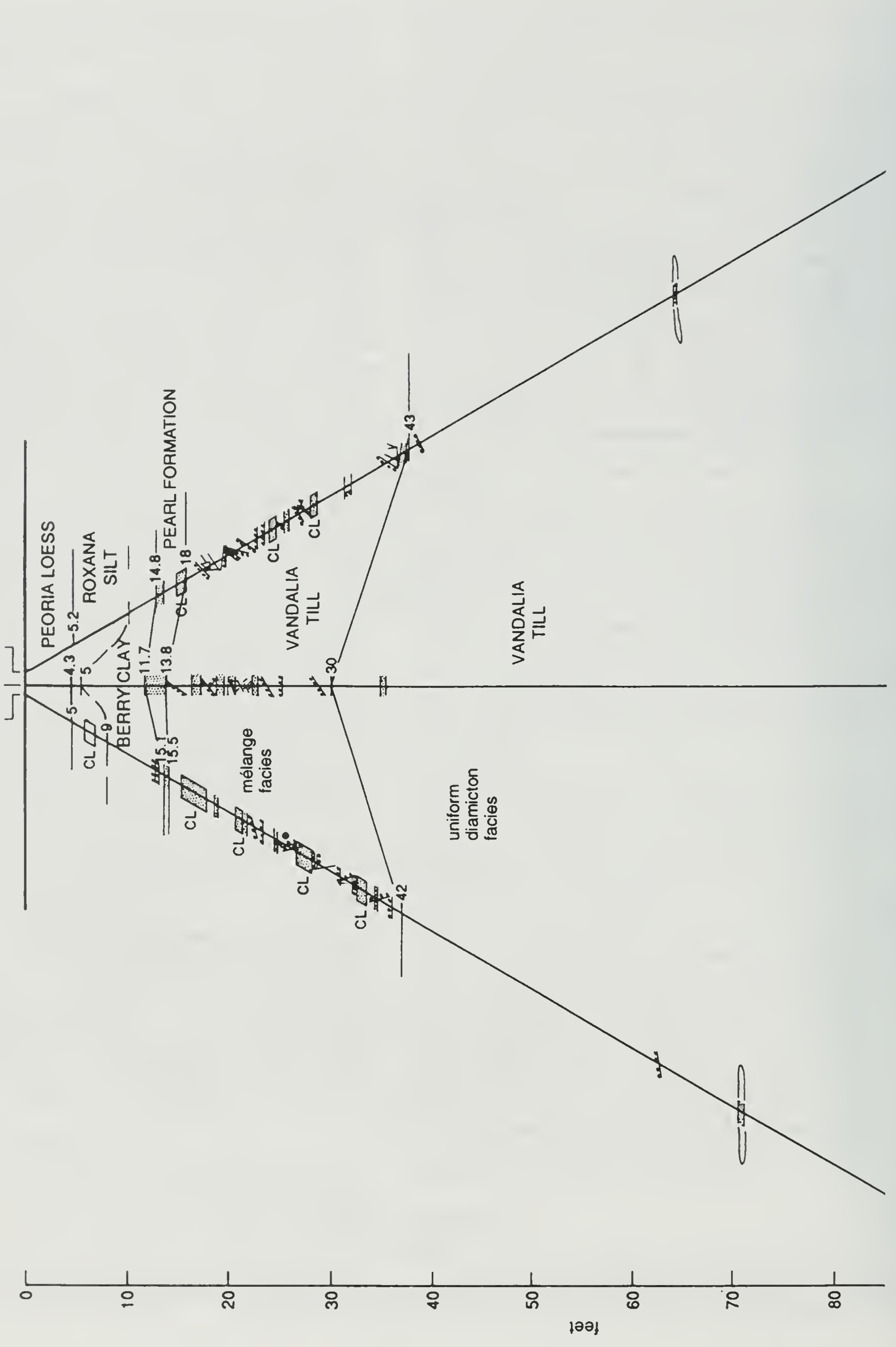
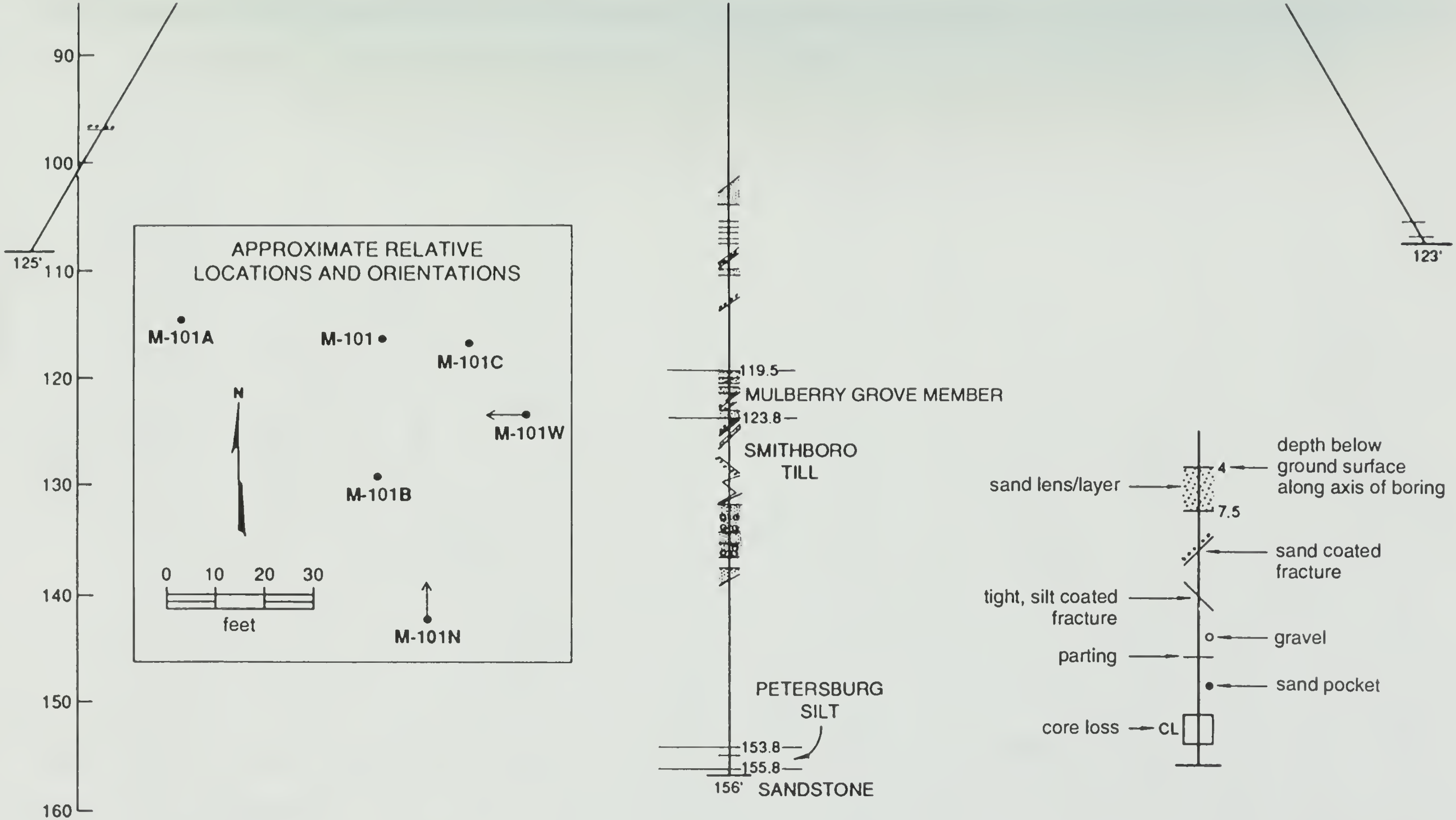


Figure 33 Sketches of outcrops CC–15 (a) and CC–16 (b) showing variable lithic discontinuities within the mélange facies of the Vandalia Till Member (from Troost and Curry 1991). Locations shown in figure 2.


M-101N
N01°45.48'E
M-101
M-101W
N89°23.29'W
PEORIA LOESS
ROXANA SILT
BERRY CLAY
PEARL FORMATION
VANDALIA TILL
VANDALIA TILL
mélange facies
uniform diamicton facies
CL
feet
0
10
20
30
40
50
60
70
80



These logs show distribution of fractures in borings M-101, M-101W, and M-101N and may not be representative of the fracture distribution across the Martinsville Alternative Site.

Significant fractures, partings, and lithologic discontinuities are shown. Other minor fractures may be present.

Orientation and angle of fractures have not been corrected for orientation of boring.

All angled borings are oriented 30° from vertical.

Figure 34 Discontinuities and lithostratigraphic contacts from the angled boring series M-101 (after Battelle Memorial Institute and Hanson Engineers, Inc. 1990a).

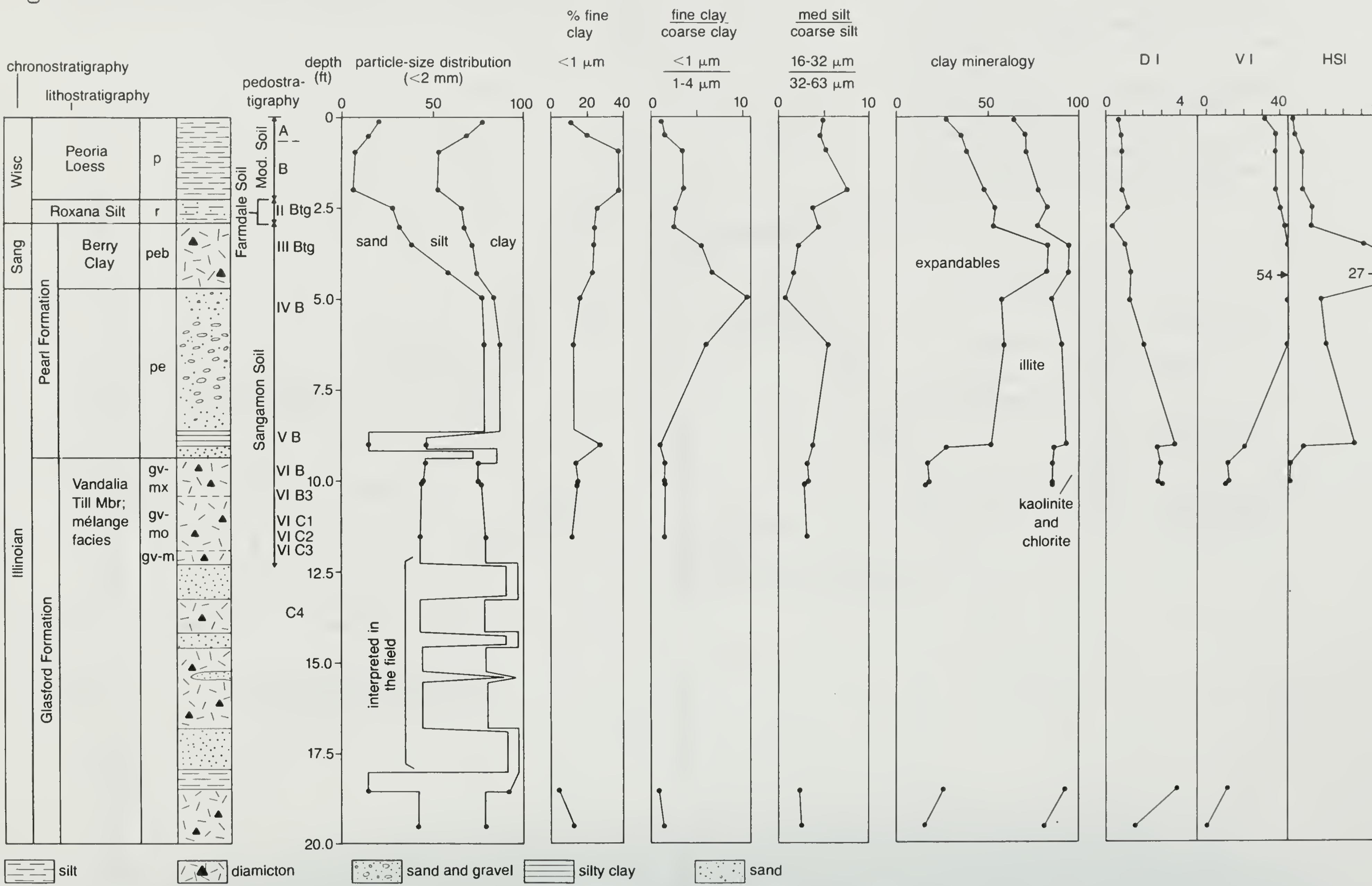


Figure 35 Lithofacies log and laboratory data from outcrop samples collected at CC–16. Location shown in figure 2.

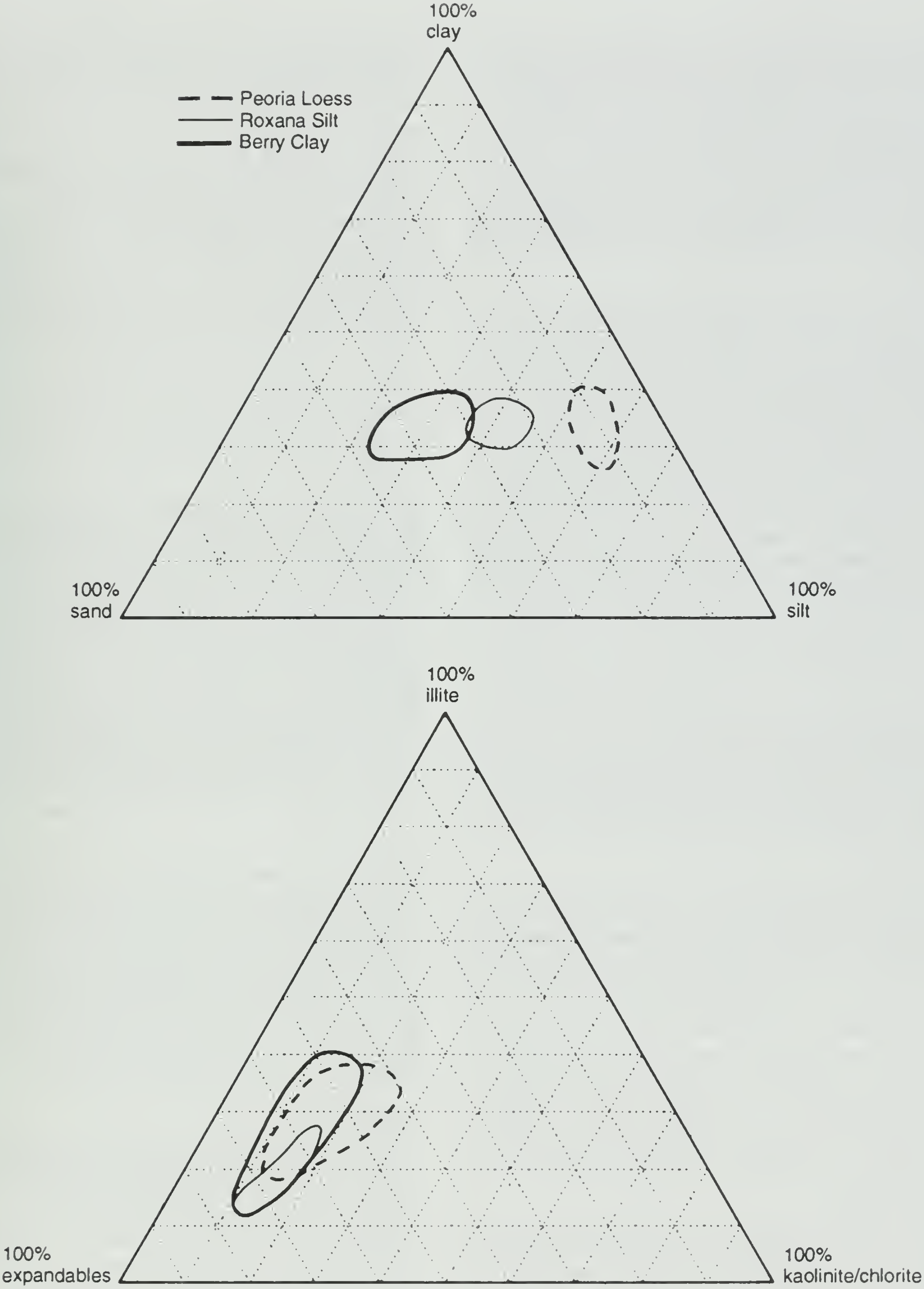


Figure 36 Ternary plots of textural and mineralogical data for surficial units at the MAS, including the Berry Clay Member, Roxana Silt, and Peoria Loess. The envelopes encompass values within 1 standard deviation of the mean.

(gv–mx in appendix) is dominated by (1) pedogenic structures, such as blocky to granular peds that have continuous clay skins (argillans), (2) reddish, brownish, or greenish hue, (3) abundant, variably swelling vermiculite and smectite (Curry 1989), and (4) relatively abundant, fine clay (as expressed by relatively large fine to coarse clay ratios (<1 μm to 1–4 μm; fig. 35). In most cases at the MAS, the Berry Clay Member is interpreted to be the Btg horizon of the Sangamon Soil developed in Pearl Formation or the Vandalia Till Member.

At greater depth in the C horizon, oxidized sediment occurs with organo-sesquioxide coatings along the faces of joints and fractures in diamicton, or as grain coats within bodies of sand and gravel. Oxidized and calcareous diamicton with relatively coarse, blocky structure occurs in the upper part of the C horizon (the C2 horizon of Follmer 1985). Oxidation of the diamicton in the C2 horizon is indicated by lighter hues compared with unoxidized diamicton (grayish brown, 10YR 5/2 compared with gray, N 5/0). It is also detected in the clay mineralogical analyses of the <2 μm fraction. The pedogenic transformation of chlorite to vermiculite results in lower kaolinite plus chlorite values (mean values for gv–mo and gv–m are 15.6 and 28.1, respectively) and greater vermiculite indices (mean values for gv–mo and gv–m are 11.4 and 5.7, respectively). In the C3 horizon, the faces of discontinuities are stained with sesquioxides, although the diamicton between the discontinuities is unweathered. Stains commonly occur in the upper parts of sand and gravel bodies often sandwiched between unaltered diamicton. The C3 horizon is as much as 20 feet thick at the MAS, extending more than 40 feet below ground surface.

Roxana Silt

Johnson et al. (1972) named the sandy silt facies of the Roxana Silt to designate a zone composed of pedogenically mixed, weathered Illinoian and Sangamonian sediment and Wisconsinan loess (Roxana Silt). The sandy silt facies of the Roxana Silt near Casey, Illinois, is described in detail by Follmer (1982). At the MAS, the Roxana is composed of pedogenically modified, leached loam, 1 to 8 feet thick. The loam contains abundant nodules and ped coatings composed of organo-sesquioxides. The mean thickness of the sandy silt facies of the Roxana Silt in the region is about 1.3 feet (Fehrenbacher et al. 1986); mean thickness at the MAS is about 3.0 feet.

The Roxana Silt is differentiated from the Berry Clay Member and Peoria Loess on the basis of particle-size distribution, stratigraphic position, and the presence of features characteristic of the Farmdale Soil. The Roxana Silt at the MAS may be sandier than in other parts of Illinois (Follmer 1982, Johnson et al. 1972) because of a potential proximal source of eolian sediment derived from the valley of the North Fork Embarras River. In general, the Roxana differs from the underlying Berry Clay Member by containing more than about 35% silt and less than 2% gravel. Roxana Silt generally can be distinguished from the overlying Peoria Loess by its content of more than 15% sand (fig. 36); the Peoria also contains little or no gravel. Clay mineralogy is not a useful differentiating criterion because the Berry Clay Member, Roxana Silt, and Peoria Loess at the MAS contain abundant expandable clay minerals (59%, 68%, and 53%, respectively; appendix; fig. 36).

The Roxana is distinguished most easily from other units where sediments are thick, such as in loess along the Illinois River valley. At the MAS, however, the Roxana Silt generally is less than 3 feet thick, possesses no primary loess character, and has physical properties similar to those of the underlying Berry Clay Member. Were it not for regional relationships, a tenable interpretation at the MAS would be that only one Wisconsinan loessial unit is present and its lower portion is pedogenically mixed with the Berry Clay Member.

Farmdale Soil

The Farmdale Soil is developed in the top of the Roxana Silt and possesses cumulic B, E, or A horizons above the Sangamon Soil. Pedogenic characteristics of the Farmdale at the MAS are similar to, but not as prominent as those of the Sangamon Soil. Typically, angular blocky structure is somewhat coarser and sesquioxide concretions are finer in the Farmdale than in the Sangamon. The Farmdale also is typically grayer than the Sangamon. At the MAS, contact between the Farmdale and the overlying modern soil generally is gradual. The contact was determined on the basis of textural differences (discussed above) between the Roxana Silt and Peoria Loess (figs. 35, 36). The Bt horizon of the modern soil, developed in Peoria Loess, is generally above the Farmdale Soil.

Wedron Formation, Fairgrange Till Member

The Fairgrange Till Member of the Wedron Formation, although absent at the MAS, is present in the Shelbyville Moraine 8 miles northwest of the study area. The moraine marks the maximum southward advance of the late Wisconsinan Lake Michigan Lobe about 20,000 years ago (fig. 1). The Fairgrange Till Member is composed chiefly of clay loam or loam diamicton and lesser amounts of sand and gravel (Ford 1970).

Peoria Loess

The Peoria Loess, named by Frye and Leonard (1951), is further discussed in McKay (1979) and Follmer (1982). At the MAS, the Peoria Loess continuously mantles the upland surface. The Peoria Loess generally is less than 6 feet thick and its mean thickness is 2.8 feet. The Peoria is composed of leached, pedogenically modified silt loam, silty clay loam, and silty clay. A sand content of less than 15% distinguishes it from the underlying Roxana Silt (fig. 36). The mean texture of the Peoria is about 5% sandier than the regional mean (Fehrenbacher et al. 1986). This textural difference may be explained by an admixture of silty loess and eolian sand derived from the North Fork Embarras River val-

ley. The modern soil developed in the Peoria Loess imparts pedogenic features such as biopores (roots, etc.), clay cutans, and subangular blocky structure.

Parkland Sand

The Parkland Sand, named and described by Willman and Frye (1970), consists of predominantly fine to medium grained sand. The Parkland Sand is as much as 5 feet thick at M–01, and only locally present along an upland corridor about 0.5 mile wide east of the North Fork Embarras River valley. Parkland Sand, probably eolian in origin, was mapped on upland surfaces outside the MAS east of the North Fork Embarras River (Lineback 1979a).

Henry Formation

Willman and Frye (1970) named and described the Henry Formation. It consists of surficial sand and gravel from late Wisconsinan glaciation and thus is restricted to the North Fork Embarras River valley adjacent to the MAS. A thick deposit of the Henry Formation occurs beyond the late Wisconsinan glacial margin in the valleys of large streams and rivers. Several terraces adjacent to the Holocene floodplain are composed of this deposit (Miller 1973, Hajic 1990). In the valley of the North Fork Embarras River, the sand and gravel facies of the Cahokia Alluvium (described below) may locally correlate with the Henry Formation. Radiocarbon ages (discussed below) indicate the sand and gravel is at least in part Holocene. Henry Formation was mapped about 7 miles north along the headwaters of the North Fork Embarras River (Lineback 1979a).

Cahokia Alluvium

Deposits in the Mississippi River valley near East St. Louis, Illinois, were described and named Cahokia Alluvium by Willman and Frye (1970). The character of the Cahokia was studied in the lower Illinois River valley (Hajic 1985, 1990) and along tributaries to the Vermilion River near Danville, Illinois (Stanke 1988). In the study area, Cahokia Alluvium occurs below wide terraces along valleys 1 to 10 feet above the modern stream beds, and in the channels of modern rivers and streams (fig. 37). Well sorted, medium grained sand constitutes the bed load of present-day streams at low flow and forms a thin mantle above the terrace sediments adjacent to the modern stream channels. This mantle was deposited during recent floods. Numerous bars along the stream channels are composed of well sorted sand or coarser rock fragments as much as 2 feet across.

The Cahokia is subdivided into a lower sand and gravel facies (c-z) and an upper silt loam facies (c-s). The sand and gravel facies, composed of uniform to stratified, coarse grained sediment, is as much as 34 feet thick at M–127. The silt loam facies, as much as 14.6 feet thick at H–1, is composed of pedogenically altered, soft, leached, uniform to vaguely laminated silt loam in the North Fork Embarras River valley. The silt loam facies is sandier in the valleys of Bluegrass Creek and Kettering Branch. The silt loam facies is interpreted to have originated as overbank sediment and as tongues of colluvium, especially adjacent to valley slopes. The lower layer of the sand and gravel facies and the upper layer of the silt loam facies of the Cahokia along the North Fork Embarras River are remarkably continuous (fig. 14). Radiocarbon ages from the Cahokia adjacent to the MAS span from 320 to 23,700 yr B.P. (discussed below). Portions of the unit may be as old as late Illinoian.

Peyton Colluvium

Deposits near Peoria, Illinois, were described and named Peyton Colluvium by Willman and Frye (1970). The unit comprises colluvial and alluvial fans associated with archaeological sites along the lower Illinois River (Hajic 1985). In the study area, the Peyton Colluvium occurs primarily at the base of slopes between the uplands and valleys of the North Fork Embarras River, Bluegrass Creek, Kettering Branch, and their tributaries adjacent to and on the MAS. The lithology of the Peyton Colluvium is similar to the lithology of the sediment from which the colluvium is derived. The local thickness of the Peyton Colluvium changes significantly as it is removed by stream erosion at the base of slopes.

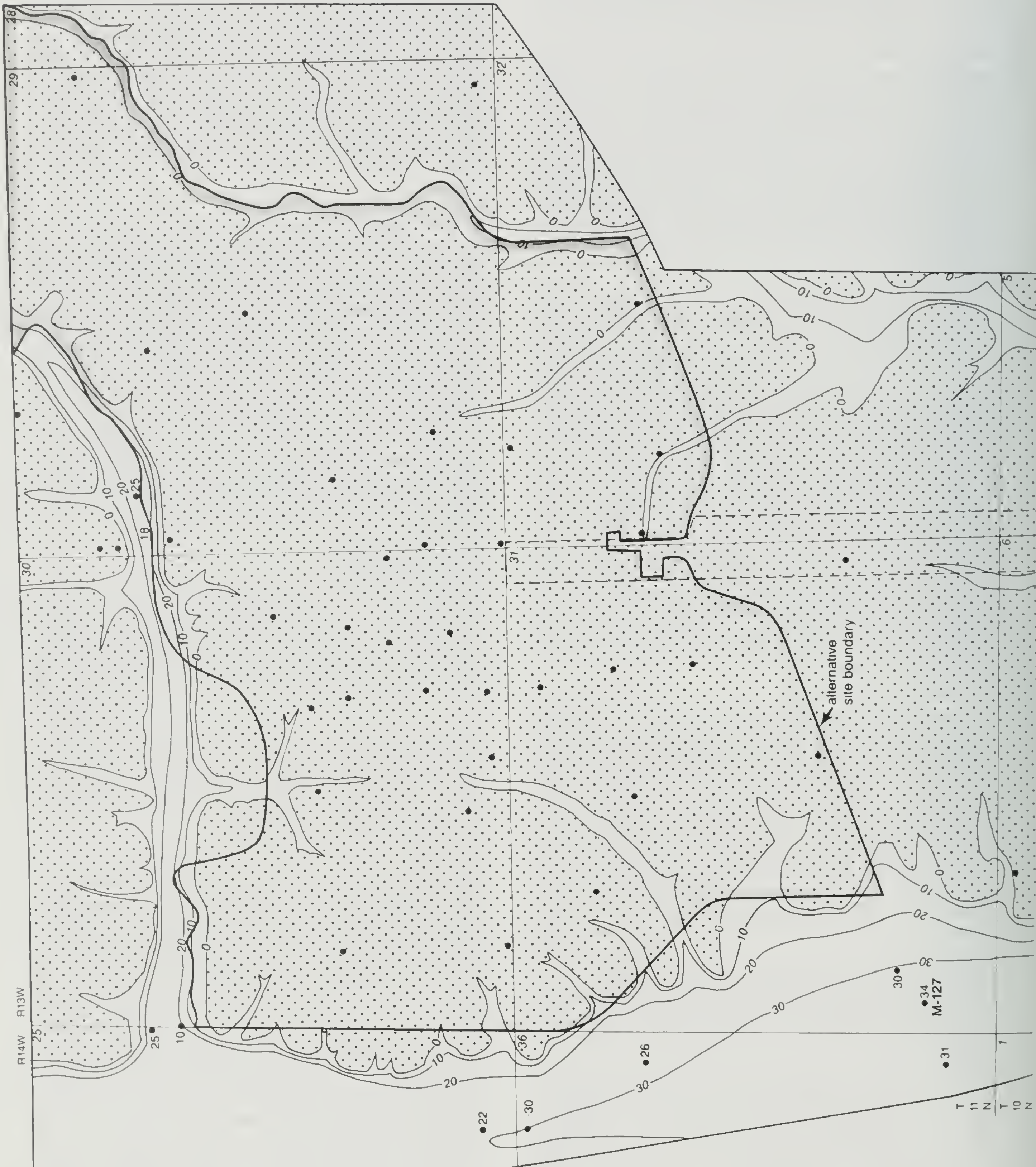
Lacon Formation

Willman and Frye (1970) named and described the Lacon Formation. This surficial lithostratigraphic unit is composed of sediment flow and landslide material. Because of the genetic definition of the Lacon Formation, its regional composition varies. Adjacent to the MAS, small earth slumps were noted along Bluegrass Creek where the stream impinged on the valley wall. The largest slump, noted in early spring 1989 at outcrop CC–16, involved 5,000 cubic feet of debris composed of reworked Vandalia Till and overlying upland units. Much of the slump material was removed by creek erosion later in the spring.

Petrographic Characteristics of Sand Units

The petrography of sand units, except Cahokia Alluvium at the MAS, was determined to aid in stratigraphic discrimination and interpretation of environments of deposition. Table 4 lists the lithologic categories counted for each sample. In general, the petrographic characteristics of the sand and gravel facies of the Martinsville sand and Pearl Formation were distinctive due to pedogenic or diagenetic grain coatings. The sand and gravel facies of the Mulberry Grove Member was not petrographically distinct from sand and gravel bodies within the uniform diamicton facies of the Vandalia Till Member.

Samples from the sand and gravel facies of the Martinsville sand consist of lithic components similar to the other units studied in detail and suggest similar provenance (fig. 38). Unique attributes of this unit include brownish coatings on the grains and nodular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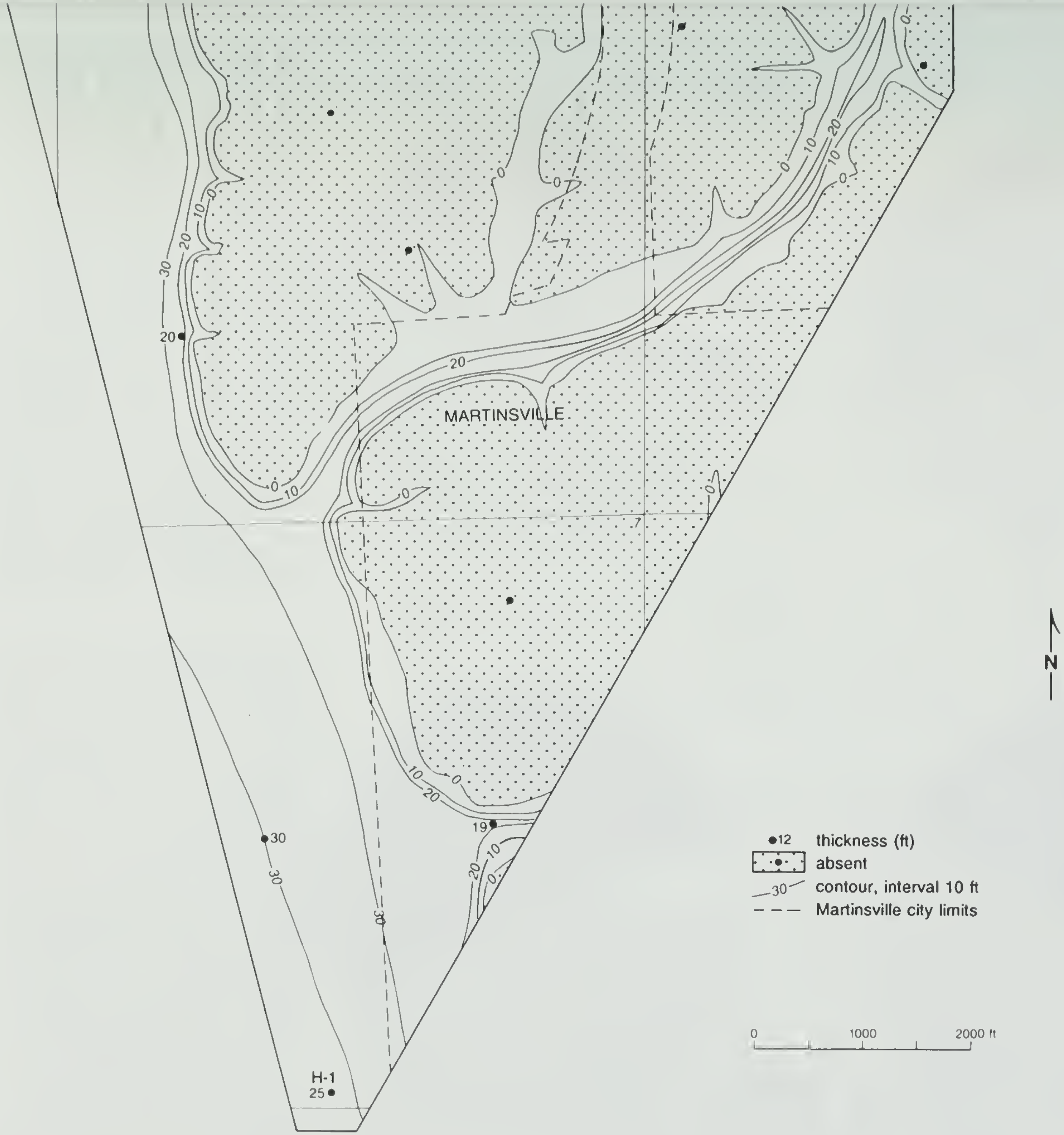


Figure 37 Thickness of Cahokia Alluvium.

Table 4 Lithic composition of sand units as interpreted from point counts of petrographic slides (from Battelle Memorial Institute and Hanson Engineers, Inc. 1990a).

	Pearl Formation		Sand bodies in the uniform diamicton facies, Vandalia Till Member		Sand and gravel facies, Mulberry Grove Member		Sand and gravel facies, Martinsville sand	
	Mean (9 slides)	Std. Dev.*	Mean (14 slides)	Std. Dev.*	Mean (20 slides)	Std. Dev.*	Mean (15 slides)	Std. Dev.*
Quartz								
Single grain	64.1	9.4	51.1	9.9	35.8	22.3	37.9	15.5
Polycrystalline	5.2	2.6	4.4	1.9	3.8	2.4	6.4	2.8
Undulatory extinction	2.7	4.4	1.5	1.6	1.1	1.1	1.3	1.2
Feldspar	6.2	2.1	4.9	1.9	3.8	3.0	5.3	2.9
Limestone								
Fine grained	1.6	2.2	5.4	1.5	9.0	5.8	5.2	3.7
Crystalline	5.7	5.9	16.7	5.8	19.3	8.8	11.9	9.3
Fossiliferous	0.1	0.3	0.6	1.0	1.1	1.6	1.5	3.3
Siliceous	0.2	0.4	4.3	4.6	9.4	5.7	3.7	3.6
Rock fragments								
Metamorphic/Igneous	4.0	2.8	3.4	1.7	5.7	3.6	5.2	3.9
Sedimentary	7.2	5.2	7.6	3.2	11.3	6.5	19.8	8.8
Iron cemented aggregates	2.8	4.2	0	0	0	0	0	0
Opaques	0.1	0.3	0.1	0.3	0.3	0.4	1.3	2.0
TOTALS								
Quartz	72.0	6.4	57.0	10.6	40.7	21.6	45.5	17.1
Limestone	7.6	7.9	27.0	8.6	38.7	16.3	22.3	17.2
Rock fragments	11.2	4.5	11.0	4.1	17.0	8.0	25.0	9.6

*Standard deviation

aggregate grains of calcareous concretions. Either attribute may be of pedogenic or diagenetic origin, but the paucity of pedogenic structures suggests the latter.

The average lithic composition of the sand and gravel facies of the Mulberry Grove Member, and of the sand bodies within the uniform diamicton facies of the Vandalia Till Member is similar. The most useful petrographic criterion for differentiating these units was sorting of lithic type per grain-size category (fig. 39). The mean value and standard deviation of quartz grains found in the various categories of sand size is 57.0 ± 10.6% in sand bodies of the Vandalia, and 40.7 ± 21.6% in the sand and gravel facies of the Mulberry Grove Member. The relatively poor sorting (i.e., greater standard deviation) of the latter unit indicates that the sand and gravel facies of the Mulberry Grove was deposited under more variable conditions of stream power and sediment load than the sand bodies in the Vandalia Till.

Samples of the Pearl Formation contain heterolithic grains of silt and fine grained sand cemented by brownish black sesquioxides. The Pearl also contains less limestone fragments than the other units examined. The microconglomerate and paucity of limestone fragments may be attributed to pedogenesis associated with the Sangamon Soil.

GEOCHRONOLOGY

The chronologic age of most lithostratigraphic units at the MAS is not well understood from on-site determinations. The age of some deposits was estimated by correlation of these units with those in areas where the chronology is better known (fig. 40). The confidence in these estimates lessens with increasing age. Along the Illinois River valley, Peoria Loess was deposited from about 25,000 to 12,500 B.P. (McKay 1979) and Roxana Silt, from about 50,000 to 30,000 B.P. (McKay 1979, Curry and Follmer 1992). Three ages from the Berry

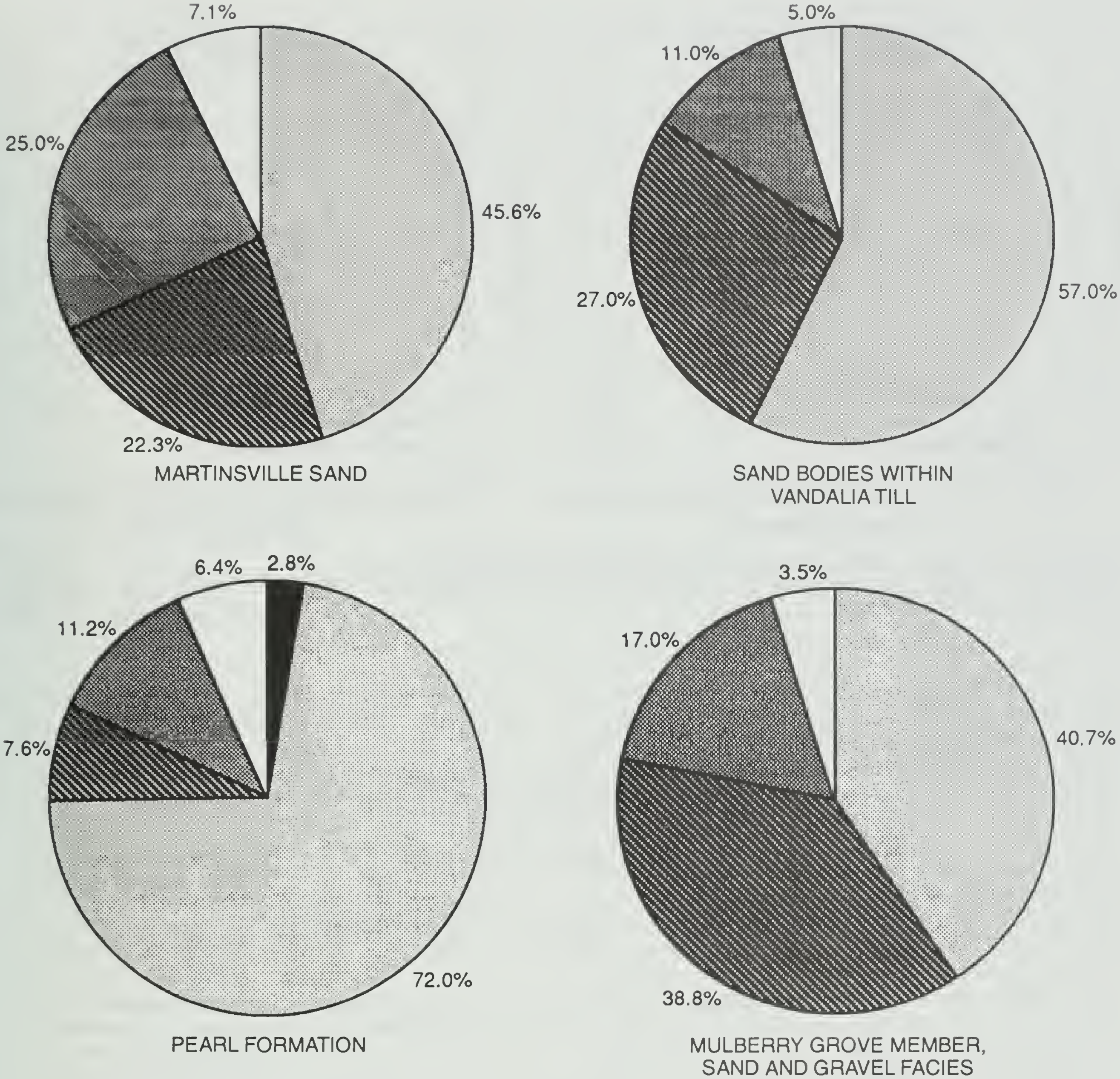
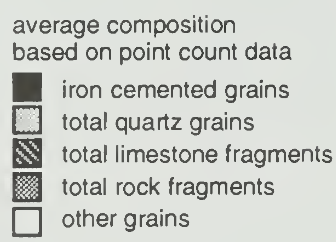
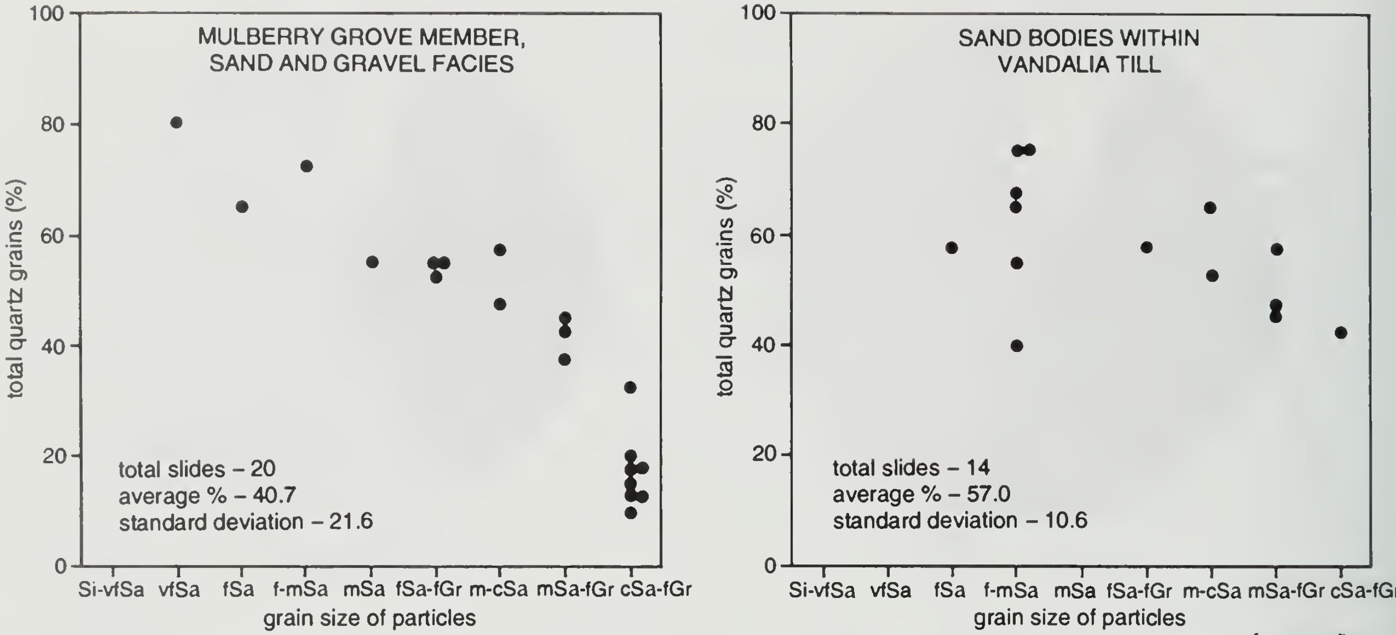


Figure 38 Average lithic composition of sand units.

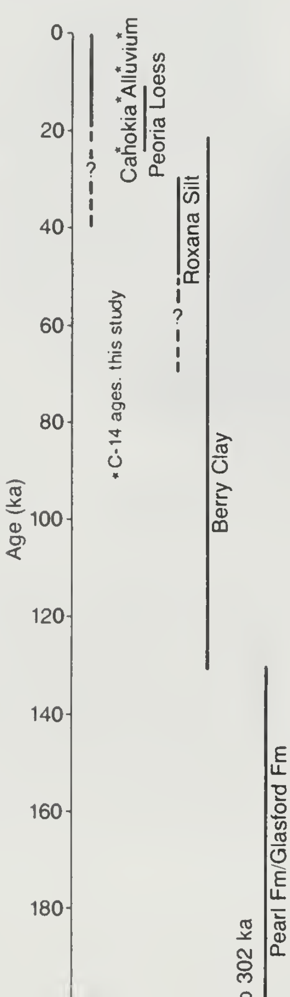




Si – silt
Sa – sand
Gr – gravel

vf – very fine
f – fine
m – medium
c – coarse

Figure 39 Percentage of quartz vs. grain size or range of grain sizes per slide from petrographic studies. Grain size ranges are positioned on the scale according to the mean particle size of each range.



Unit	Age (ka)	Reference	Basis of age/region or site
Peyton Colluvium	not determined	—	—
Cahokia Alluvium	23.7 - 0.3	this study	^{14}C ages on wood adjacent to MAS (0.3 and 23.7 ka)
Peoria Loess	25.0-12.5	McKay 1979, Follmer et al. 1979	^{14}C ages on wood, lower Illinois River valley, Athens Quarry
Roxana Silt	50.0-30.0	McKay 1979, Curry and Follmer 1992	^{14}C ages on organic-rich sediment, wood and snails, lower Illinois River Valley, Athens Quarry
Berry Clay	130-21	**Johnson, Glass et al. 1971**	^{14}C age on organic-rich clay, Shelbyville (21 ka)
		Blackwell et al. 1990	Electron-spin resonance age on mastodon molar, Hopwood Farm (130-73 ka)
		Richmond and Fullerton 1986	Orbitally tuned marine records (132-70 ka)
Pearl Formation, Glasford Formation, Petersburg Silt	302-132	Richmond and Fullerton 1986	Orbitally tuned marine records
Banner Formation	788-302	Richmond and Fullerton 1986	Orbitally tuned marine record, Matuyama-Bruhnes magnetochron (≈ 788 ka)

Figure 40 Estimation of unit ages based on data from outside the MAS.

Table 5 Amino acid measurements of gastropod shells (from William McCoy, University of Massachusetts, Amherst, personal communication 1989).

Core or boring (depth, ft)	Unit	Genus	Lab no. AGL-	Analyses	Free hydrolysate	Total hydrolysate
M–07 (118.0)	Mulberry Grove, silt facies	*Succinea*	1324	4	0.35 ± 0.01	0.25 ± 0.01
M–14 (113.5)	Smithboro Till Member, silt loam diamicton facies (inclusion of Petersburg Silt)	*Stenotrema*	1325	2	0.27	0.15
M–14 (147.0)	Petersburg Silt	*Pomatiopsis*	1326	2	–	0.19
CC–11	Smithboro Till Member, silt loam diamicton facies	*Hendersonia*	1327	3	0.30	0.17
CC–11	Smithboro Till Member, silt loam diamicton facies	*Stenotrema*	1328	2	0.30	0.19
CC–11	Smithboro Till Member, silt loam diamicton facies	*Anguispira*	1329	2	0.31	0.13

Clay include ca. 130 to 73 ka (Blackwell et al. 1990), 41,770 ± 1100 yr B.P. (ISGS-684; Follmer 1983), and 21,400 ± 1000 yr B.P. (ISGS-46; Johnson, Glass et al. 1971). The older ages are considered to be more representative of the regional age of the Berry Clay than the age of 21,400 yr B.P., which may have been collected from a younger stratigraphic unit (W. H. Johnson, University of Illinois, personal communication 1990). Richmond and Fullerton (1986) estimated the age of Illinoian deposits to be 300,000 to 130,000 yr B.P. by extrapolating from orbitally tuned, oxygen isotope deep-sea records.

The geochronology of sediments deposited during the pre-Illinoian and Yarmouthian Ages are not well known. Pre-Illinoian lacustrine sediments near Danville, Illinois, and in adjacent western Indiana have normal and reversed paleomagnetic polarity (Johnson 1986). The last change from normal to reversed polarity is the Matuyama-Brunhes magnetochron that occurred about 788,000 years ago (Richmond and Fullerton 1986). If the Casey till member correlates with the Hillery Till Member of the Banner Formation in the Danville area, as suggested by Kettles (1980), it is less than 788,000 years old.

Correlation of the Petersburg Silt with other early Illinoian deposits is supported by measurements of amino acid racemization of gastropod shells. The amino acid racemization reaction used in this study was the measurement of the relative amount of alloisoleucine (Aile) and isoleucine (Ile) (McCoy 1987). Shells of living gastropods contain only isoleucine. Through geologic time, isoleucine epimerizes to the diastereomer alloisoleucine, and the ratio, expressed as Aile/Ile, increases to an equilibrium value of 1.30 ± 0.05. Although the rate of this reaction is known, the temperature history of the sample must be known within 1% variance through time to calculate an age of about 30% accuracy. The temperature history generally cannot be assumed or measured with such precision (McCoy 1987). Thus, determining ages using this technique at the MAS was not attempted.

If deposits in a geographic area have experienced similar temperature histories, measurements of amino acid racemization can be used for relative age correlations. Typically, the data are presented as Aile/Ile in the free and peptide-bound amino acids and in the total amino acid hydrolysate (Clark et al. 1989), or as Aile/Ile in the total hydrolysate relative to Aile/Ile in the free hydrolysate. Six amino acid racemization measurements were made on gastropods from core collected at the MAS and from units in outcrop CC-11, including Petersburg Silt, and the Smithboro Till Member and Mulberry Grove Member of the Glasford Formation (table 5). The results indicate that these units correlate with Illinoian deposits near the type sections (Miller et al. 1988) and other sediments in western Indiana (fig. 41; Miller et al. 1987).

Four radiocarbon ages were determined from wood fragments and organic debris in Cahokia Alluvium adjacent to the MAS (table 6). Two ages from sediment in the valley of the North Fork Embarras are Holocene, including an age of 8,370 ± 300 yr B.P. (ISGS-2176) from small woody fragments and powdery organic-rich debris found at the contact between the sand and gravel facies and silt loam facies of the Cahokia Alluvium. A fragment of hickory wood (L. R. Follmer, ISGS, personal communication 1990) in alluvium adjacent to the North Fork Embarras River yielded an age of 320 ± 70

Table 6 Radiocarbon ages from Cahokia Alluvium at the MAS.

Age	ISGS lab no.	Material	Location	Depth (ft)
320±70	2073	wood (hickory)	CC–18, North Fork Embarras River valley	4.5
8,370±300	2176	unidentified wood fragments	H–1, North Fork Embarras River valley	14.2
14,490±140	2024	wood (spruce)	M–120, Bluegrass Creek valley	10.8–11.2
23,720±300	2113	wood fragments plus organic-rich clay	CC–17, Bluegrass Creek valley	at creek level (about 590 ft elevation)

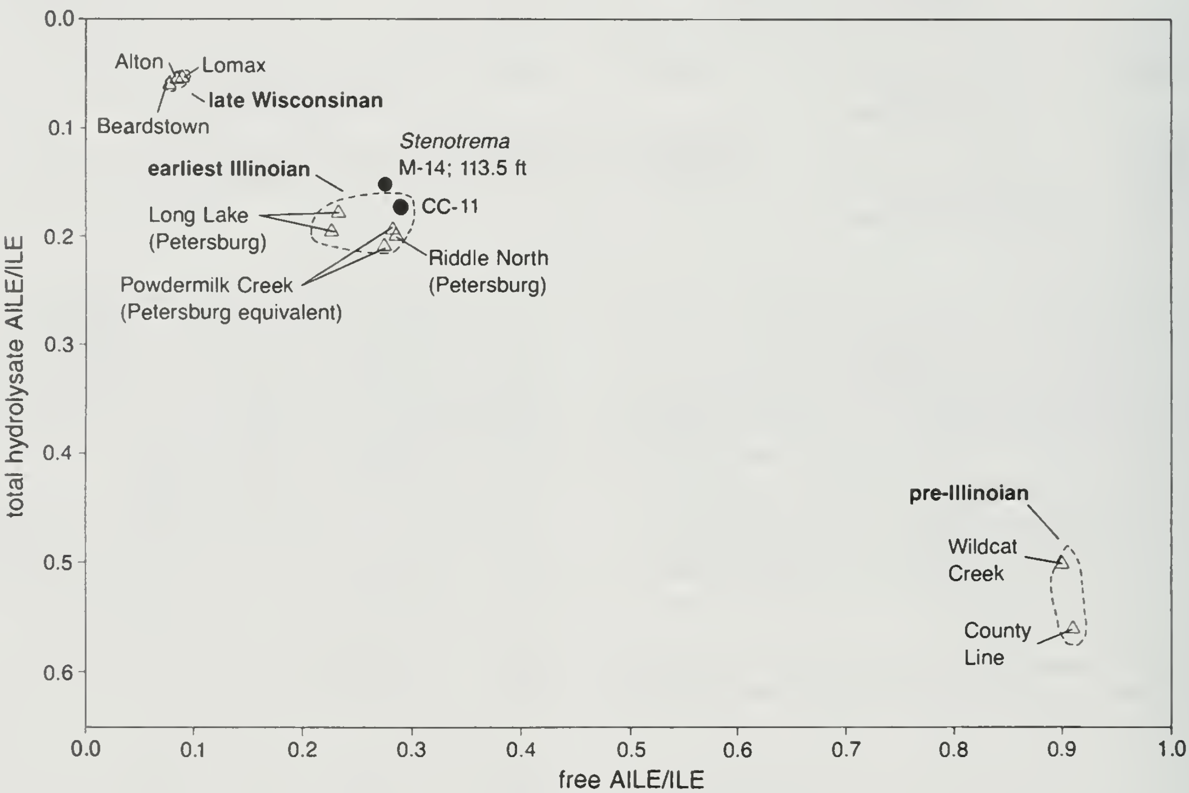


Figure 41 Plot of Aile/Ile in the total hydrolysate vs. Aile/Ile in the free hydrolysate of *Stenotrema* showing that samples from the study area correlate with Petersburg Silt near the type area.

yr B.P. (ISGS-2073). The sample, taken from a depth of 4.5 feet at outcrop CC–18 (fig. 2), provided a minimum age for the broad terrace surface adjacent to the present-day streams of Bluegrass Creek and the North Fork Embarras River. Corrections of the radiocarbon age by Stuiver and Pearson (1986) put the age in calendar years between 1474 and 1648 A.D. The age also indicates that potential archeological sites in the valley bottoms may be buried by thick alluvium.

Two radiocarbon ages from the Cahokia in Bluegrass Creek are late Wisconsinan. A coniferous wood fragment found in a buried, organic-rich horizon along Bluegrass Creek at exposure CC–17 yielded an age of 23,720 ± 300 yr B.P. (ISGS–2113). Well preserved, coniferous wood fragments (probably spruce) from a depth of 10.8 to 11.2 feet at boring M–120 (fig. 2) yielded an age of 14,490 ± 140 yr B.P. (ISGS–2024).

QUATERNARY GEOLOGICAL HISTORY AND ENVIRONMENTS OF DEPOSITION

The glacial stratigraphy of the MAS is representative of Illinoian deposits in central Illinois. Pre-Illinoian till units are not present at the site, but they are found adjacent to the site. The large database for the MAS allows detailed characterization of several units, including their thickness and distribution within two buried bedrock valleys. Interpretation of the environments of deposition of most units is limited to what can be inferred from examination of core and isopach maps.

Pre-Illinoian

The age of the regional buried bedrock valley system is uncertain, but it is, in part, pre-Yarmouthian because Lierle Clay occurs near the base of the bedrock valleys. Regional evidence indicates that pre-Illinoian ice probably modified a preexisting drainage system primarily by valley widening (Kempton et al. 1991), and by effectively removing drainage divides with low relief. Although pre-Illinoian tills are not present at the MAS, the Casey till member of the Banner Formation is present about 10 miles north, east, and west of the MAS (CC–11, fig. 1; MacClintock 1929, Kettles 1980, Ford 1970, Fox 1987). Other Banner tills have been described near Danville, Illinois (Johnson 1964, Johnson, Gross, Moran 1971, Johnson et al. 1972).

Early Illinoian Martinsville Sand and Petersburg Silt

The succession of sediments at the base of the buried bedrock valleys was deposited primarily during the early Illinoian. Yarmouthian Lierle Clay is present along the flanks, but not along the bottoms, of the buried bedrock valleys beneath and adjacent to the MAS. No more than 25 feet of downcutting is inferred to have occurred during deposition of the overlying Martinsville sand when earliest Illinoian streams were at or near the base of the Martinsville and the North Fork Embarras bedrock valleys. These buried bedrock valleys are now filled with the thickest known occurrences of several Illinoian units: the Petersburg Silt, and the Smithboro Till, Mulberry Grove, and Vandalia Till Members of the Glasford Formation.

The basal deposit of the succession, informally named Martinsville sand, is composed of colluvium, alluvium, and lacustrine sediment. Poorly expressed pedogenic features, in addition to coniferous wood fragments, indicate that the Martinsville sand accumulated under cool climate at the beginning of the Illinoian Age. Features or products characteristic of interglacial weathering, such as rounded subangular blocky soil structure, cutans, krotovina (crayfish burrows filled with black, clayey sediment; Follmer et al. 1979), and abundant clay particles <1 μm in diameter, are not evident in any facies of the Martinsville sand. Typical changes in clay mineralogy along weathering profiles, such as loss of chlorite and an upward increase in interstratified or expandable clay minerals (Willman et al. 1966, Curry 1989), also are lacking. These characteristics are common in the Lierle Clay (figs. 9, 10) and the overlying Berry Clay Member (fig. 35), both of which were pedogenically modified during interglacial episodes.

Weakly developed soils, pulmonate gastropods, concentrations of coniferous wood fragments, silt content, and laminations collectively indicate that the Petersburg Silt was deposited in a slackwater lake under periglacial conditions (Curry and Follmer 1992). The slackwater lake in the Embarras River valley formed during the early Illinoian as the level of glacial meltwater and fluvial sediment rose in the ancient Wabash River valley. As an analogy, late Wisconsinan sediment, mapped as Equality Formation and deposited in ancient Lake Embarras (Frye et al. 1972), occurs about 20 miles south of Martinsville along the Embarras River (Lineback 1979a).

Illinoian Glasford Formation — Environment of Deposition of Diamicton (Till)

Overlying the Petersburg Silt, till members belonging to the Glasford Formation are the thickest and most widespread lithostratigraphic units beneath the MAS. Special discussion of their genesis helps to explain lithologic features, physical characteristics, and distribution across the site. Generally, three types of till related to processes of deposition are recognized. They are lodgement, deformation, and meltout tills. Determining what processes predominated during till deposition requires careful study of outcrops or core because sedimentary structures characteristic of one process may have been modified by another process (Boulton 1987, Hicock 1990).

Lodgement and deformation tills are interpreted to have been deposited by active ice. Lodgement till results from debris released at the base of a sliding glacier. Deformation till results from the plastic behavior of sediment beneath the glacier as it is moved by the shearing force of the glacier. This underlying sediment is not incorporated into the glacial ice. Lodgement till commonly is interpreted to have been deposited by sliding "warm-based" glaciers that abraded bedrock surfaces, or covered paleosols or proglacial sequences with little or no deformation (Boulton 1972). Evidence of deposition by a shearing or sliding glacial bed in a lodgement environment includes bullet-shaped cobbles, strong pebble fabric, and U-shaped channels filled with sand and gravel in diamicton (Eyles 1983, Drewry 1986, Johnson and Hansel 1990).

The theory that till deposition results from deforming beds was recently advanced by Boulton (1987), Boulton and Hindmarsh (1987), Alley et al. (1987), and Alley (1991). Many tills thought to have been deposited by lodgement are now thought to have been deposited during the pervasive shear in a deforming bed. Some

attributes thought to be diagnostic of lodgement may be reinterpreted as features that support the deforming-bed theory. For example, cobble pavements (or stone lines), interpreted as partially eroded lag deposits by advocates of the lodgement process, may be reinterpreted as a lag deposit of a deforming bed (Clark 1991).

Deformation till includes masses of sediment in which the primary sedimentary structure or sequence has been disturbed (Boulton 1987). Deformation till contains abundant fragments of underlying lithologies, and the lower contact is erosional as indicated by truncated subsequences. Deformation and lodgement may be closely related; for example, diamicton originally deposited by lodgement processes may be deformed later.

Meltout till contains evidence for passive melting of interstitial ice. Passive melting may result in intercalated deposits of sorted sediment and diamicton modified by soft-sediment deformation. Examples of sedimentary structures associated with meltout till are silt layers draped over cobbles or boulders (Shaw 1988). Meltout till may be deposited in a subglacial environment or in the upper portion of an ablating glacier, from which it subsequently may be redeposited by mass wasting processes, such as sediment gravity flow (Lawson 1982).

Smithboro Till Member

The Smithboro Till Member of the Glasford Formation was deposited by the earliest Illinoian glacier in the region. The silt loam diamicton facies of the Smithboro is characterized by its great thickness and abundant inclusions of weathered bedrock, Martinsville sand, and most commonly, Petersburg Silt. Well preserved fossil gastropods in the Smithboro suggest that underlying sediment was incorporated as blocks with little internal deformation. Shearing also is indicated by strongly developed platy structure imparted by crude layering of silt loam and organic-rich, silty clay loam. These features are suggestive of remolding of primary sediment and associated structures.

The great thickness of the silt loam diamicton facies of the Smithboro at the MAS probably is due to incorporation or reworking of Petersburg Silt, which was at least 50 feet thick in the bedrock valleys before the earliest Illinoian glacier covered the area. Several deformational processes may account for the thick sections of lacustrine silt incorporated in both facies of the Smithboro (figs. 24, 25). For example, a cold-based glacier may have incorporated frozen Petersburg Silt, or alternatively, a warm-based glacier may have deformed normally or underconsolidated, saturated sediment. Differences in texture of the silt loam diamicton facies may be explained by relative degrees of shearing and remolding of sediment.

The loam diamicton facies is more uniform than the silt loam diamicton facies with respect to texture and structure. These differences may be explained by the deforming-bed theory. Deposition of the loam diamicton facies may have occurred during more pervasive shear than the deposition of the silt loam diamicton facies. Alternatively, the loam diamicton facies may have been deposited by lodgement or regelation (Drewry 1986). In either scenario, the composition of the sediment at the base of the glacier changed as the local silty and expandable clay-rich sediment became covered with till and was not re-entrained by the glacier. Composition of sediment higher in the sequence, therefore, was influenced by proportionally more far traveled sediment. The result is a till composition in the loam diamicton facies that generally is less silty and contains more illite relative to expandable clay minerals than till lower in the sequence.

Mulberry Grove Member

The distribution and physical characteristics of facies in the Mulberry Grove Member indicate deposition in subaerial proglacial and ice marginal or subglacial environments, but primarily in the latter (fig. 42). Evidence for these environments abruptly changes laterally and vertically. Successions that, in part, are composed of the pedogenically modified and fossiliferous silt facies (such as seen in core from borings M–03, M–07 [fig. 24], and M–111) are interpreted to have been deposited subaerially in a proglacial environment. Successions composed of diamicton and unaltered gray silts that have a Vandalia-like mineralogy or texture are interpreted to have been deposited in subglacial or ice marginal environments. Because of the similar mineralogy of this part of the Mulberry Grove and Vandalia, they are interpreted to have been deposited during the same glacial advance. Evidence for the abrupt changes in depositional environments is illustrated by features shown in cross section A–A′ (fig. 3). Subaerial proglacial environments are indicated by pedogenically altered silt in the Mulberry Grove Member at M–07, but immediately to the west beneath CLK–02–03 and M–101, subglacial erosion is indicated by truncation of the Smithboro Till by the Mulberry Grove and Vandalia Members.

A thick deposit of Mulberry Grove Member occurs under the east part of the modern North Fork Embarras River valley adjacent to the MAS (figs. 14, 26), and consists of interbedded diamicton and sand and gravel. The topography of the lower surface of the Mulberry Grove Member (fig. 27) indicates that most of these sediments may have been deposited in subglacial or ice marginal drainageways associated with the glacial advance that deposited the Mulberry Grove and Vandalia Till Members. Comparison of surface relief at the base of the Mulberry Grove Member (fig. 27) with that of the Vandalia Till Member (fig. 43) shows that the final phases of deposition of the Mulberry were generally aggradational.

Uniform Diamicton Facies, Vandalia Till Member

The second advance of Illinoian ice in the region deposited the Vandalia Till Member and part of the Mulberry Grove Member of the Glasford Formation. The homo-

geneity of texture and lack of primary or deformed sedimentary structure suggest that the uniform diamicton facies of the Vandalia was deposited by lodgement (Eyles 1983, Ashley et al. 1985) or in a pervasively deforming bed (Alley et al. 1987).

The genesis of anomalously thick Vandalia and deep Mulberry Grove sand and gravel near M–112 and CLK–02–03 (fig. 11) is speculative. Such a shallow cone (apex down) filled with glacigenic diamicton has not been described in the literature. Truncation of units indicate the cone is an erosional feature possibly formed in concert with the channel that occurs on the surface of the Smithboro Till Member (fig. 27). Present data do not allow specific interpretation of the genesis of these features (i.e., subglacial, ice marginal, or glaciofluvial erosion).

Mélange Facies, Vandalia Till Member

The mélange facies of the Vandalia Till Member was deposited by a combination of subglacial or ice marginal and supraglacial processes, and modified by passive loading and dewatering of relatively stagnant, debris-rich ice. At outcrop CC–16, subparallel, discontinuous layers, lenses, pods, and convoluted laminae of well sorted, medium grained sand as much as 3 feet thick and 30 feet long, are interbedded with layers of loam diamicton and uniform silt (figs. 33b, 45). The upper contacts of the sand layers commonly are irregular and wavy, which possibly was caused by soft sediment deformation during deposition and dewatering. The sand bodies (or "rafts"; Ruszczynska-Szenajch 1987) may have been incorporated into the glacier bed in the frozen state, and then transported to the site in a deforming bed (Menzies 1990a, b). Shearing during and after deposition destroyed any primary bedding structures.

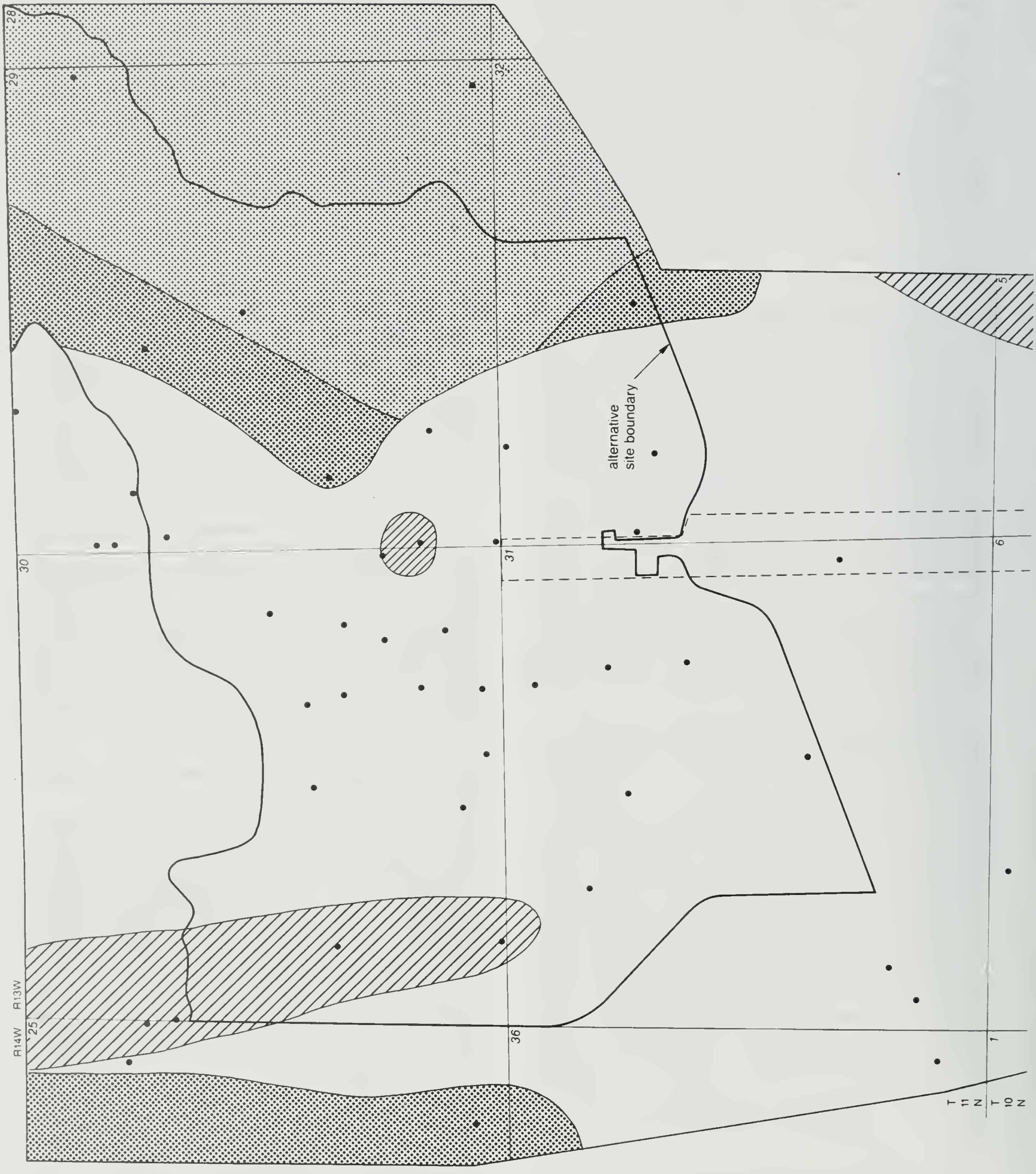
The soft-sediment deformation mentioned above resulted in a relatively weak macrofabric; therefore, the diamicton is interpreted, in part, as a meltout till. The loam diamicton above and below the sand layers at outcrop CC–16 contains numerous wavy sand partings, and yields pebble macrofabrics with poorly expressed preferred orientations (S1 values of 0.58 and 0.66 for macrofabrics A and B, respectively, in fig. 44). For a discussion of the interpretation of pebble macrofabric data, see Lawson 1982. Evidence for deposition by primarily lodgement processes is lower in the section, where the mélange facies yields a pebble fabric (macrofabric C in fig. 44) with a strong preferred orientation (S1 value of 0.81) of approximately S 32° W, the inferred direction of ice movement. The diamicton also contains abundant striated, bullet-shaped cobbles and discontinuous cobble-rich layers. Such characteristics are interpreted to indicate deposition by lodgement (Eyles 1983, Johnson and Hansel 1990) or possibly at the base of a deforming bed (Clark 1991). Thus, the mélange facies at CC–16 appears to have been deposited in a stagnating, ice-marginal environment as lodgement till, or initially deposited in a deforming bed and later deposited or modified by meltout processes.

The mélange facies at outcrop CC–15 consists of irregularly shaped pods of gravelly sand that are associated with thin layers of loam diamicton (fig. 46). Mixing of gravelly sand and diamicton did not occur, although diamicton layers are commonly less than 0.1 inch thick. Brittle fracturing of the sand and gravel, followed by filling of the fractures with fluid diamicton, may be explained by high hydrostatic pressure and partial dewatering of frozen sediment during deposition. Because a larger volume of ice or water would be in contact with grain surfaces in the diamicton than with those in the sand and gravel, it is possible that, with loading, the interstitial water in the diamicton was fluid, while the interstitial water in the sand and gravel remained frozen. Under great hydrostatic pressure and radial tensional shear stress, the bodies of sand, gravel, and ice may have deformed as a brittle solid, while the surrounding diamicton was sufficiently fluid to flow in the voids between fracture faces.

The specific mechanisms that formed the discontinuities in the mélange facies are not well understood, but multiple modes or episodes of formation probably occurred. The genesis of fracturing and discontinuities in the mélange facies can be divided into primary and secondary mechanisms. Primary mechanisms likely to have affected the mélange facies include deformation and faulting during compaction and dewatering, differential compaction, and stresses from loading and unloading of ice or ice movement (Connell 1984). Secondary mechanisms likely to have affected the mélange facies include desiccation cracking, stress release, weathering, periglacial processes, and ice-wedge formation under ancient permafrost conditions. The vertically oriented sand-filled joints at CC–15 (fig. 33a) may have formed as ice-wedge casts during the late Illinoian. Battelle Memorial Institute and Hanson Engineers, Inc. (1990a) provide a more detailed discussion of fracture genesis and character at the MAS.

Late and Post-Illinoian Deposits, Weathering, and Development of Stream Network

Upland surfaces Sand and gravel and patchy lacustrine sediments belonging to the late Illinoian Pearl Formation were initially deposited on upland surfaces during melting of the glacier that deposited the Vandalia Till Member. These sediments were partly buried by colluvium and weathered during the Sangamonian Age. Composed of soft, expandable, clay-rich diamicton, this sediment is the Berry Clay Member. Weathering and bioturbation of surficial sediment continued as the first Wisconsinan loess (Roxana Silt) was deposited at the MAS. Less sand and finer pedogenic features in the lower part of the overlying Peoria Loess indicate that less bioturbation and weathering occurred during the late Wisconsinan than during the Sangamonian and early to middle Wisconsinan. The most likely origin of the Parkland Sand and the relatively high sand content of the loess at the MAS (compared to the regional mean of Fehrenbacher et al. 1986) was locally sandy alluvium in the floodplain of the North Fork Embarras River. For


alternative
site boundary
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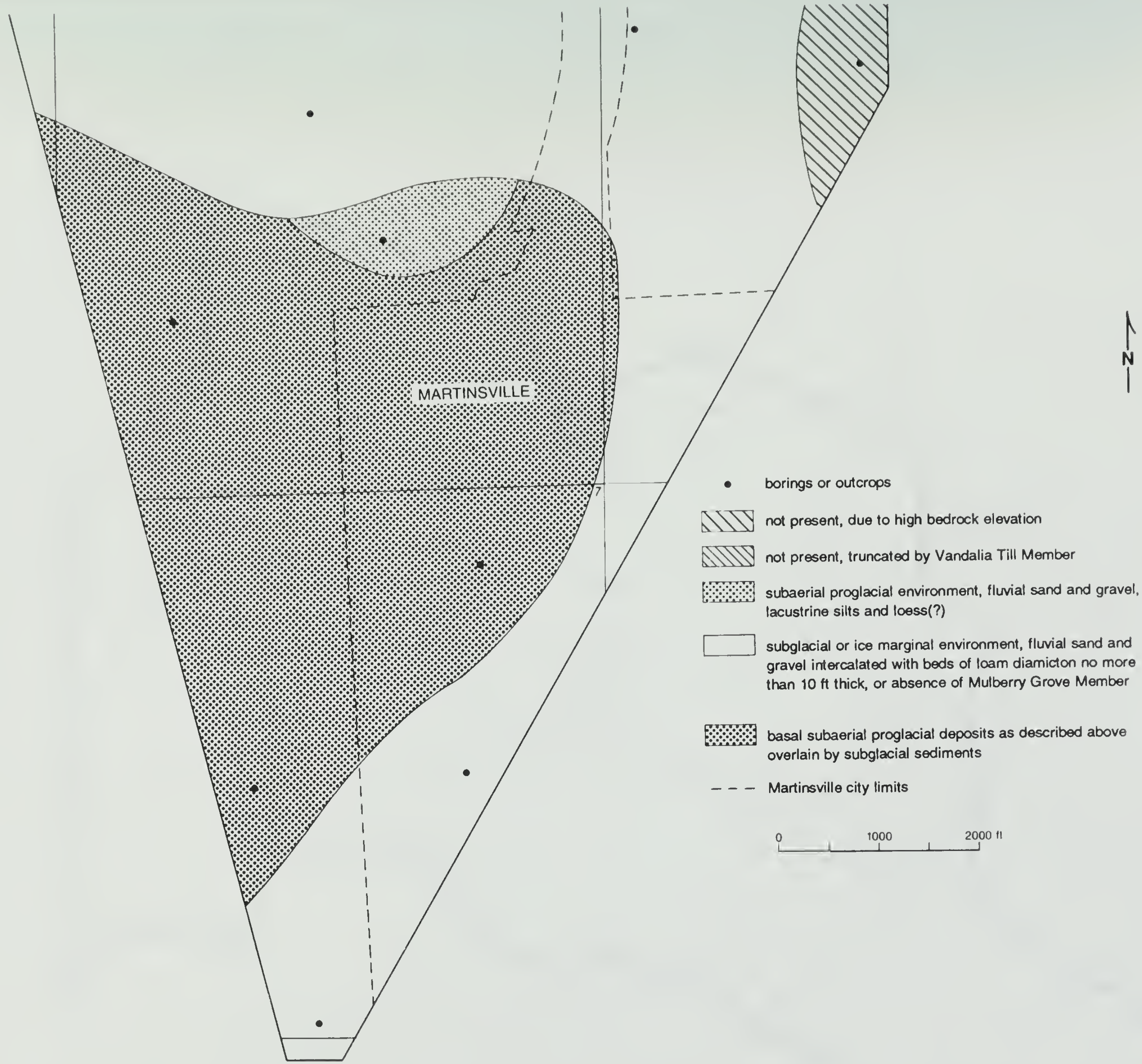
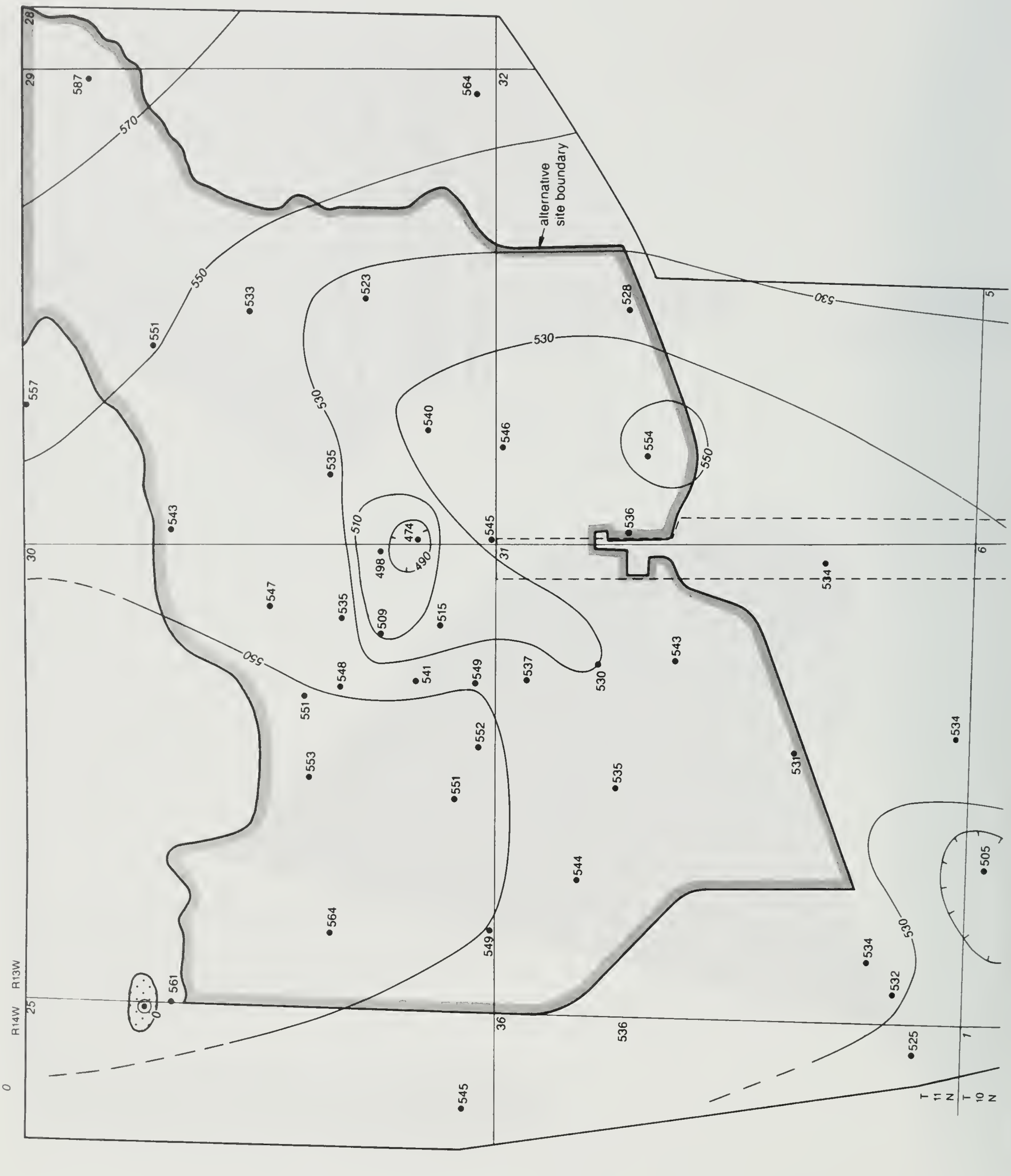


Figure 42 Interpreted environment of deposition of the Mulberry Grove Member, Glasford Formation.


alternative site boundary
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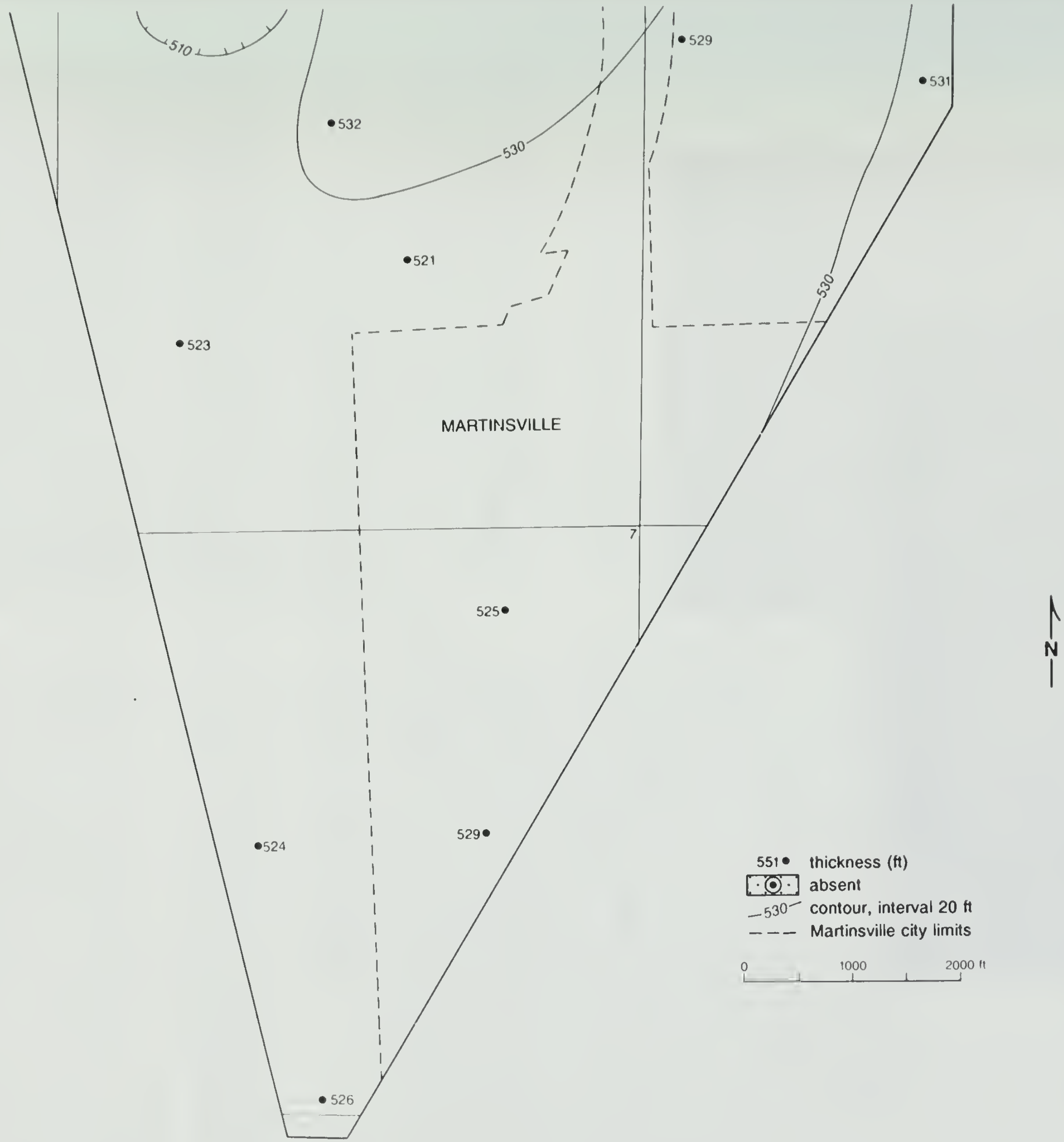

Figure 43 Elevation of the lower surface of the Vandalia Till Member, Glasford Formation.

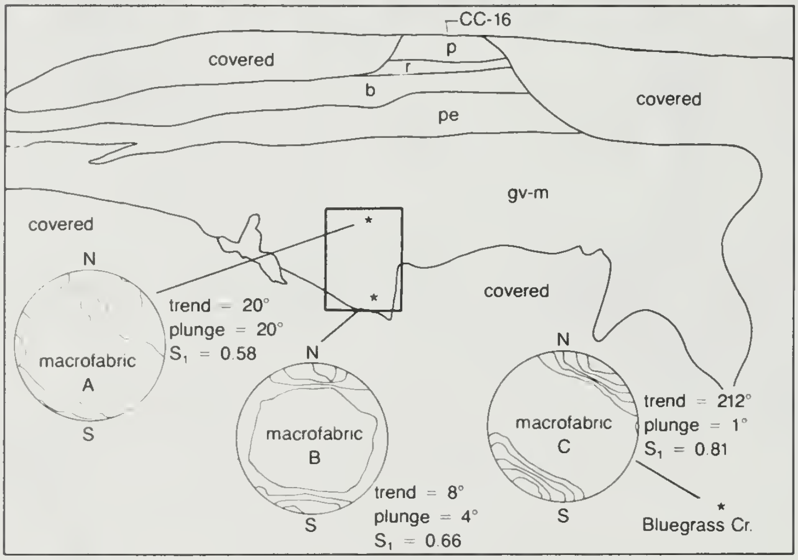

Figure 44 Outcrop CC–16 along Bluegrass Creek, immediately north of the MAS, and pebble macrofabrics from the mélange facies of the Vandalia Till Member, Glasford Formation.

about the last 10,000 years, the mantle of late glacial and postglacial sediment has been weathered under a climate similar to that of today (Willman and Frye 1970).

Upland slopes Throughout the study area, the Sangamon Soil occurs on uplands, as well as along gentle valley slopes extending to about 30 feet above the major streams. The depth of leaching and other pedogenic alteration below these slopes is shallower than on the uplands. The thin mantle of Wisconsinan loess above the Sangamon Soil on slopes indicates that sediment was transported during the late Sangamonian (Johnson et al. 1972). Erosion has stripped any postglacial loess or upper soil horizons of the Sangamon Soil from slopes extending from major floodplains to about 30 feet above the floodplains.

Valleys Development of the drainage network on and immediately adjacent to the MAS may have begun after deposition of the Pearl Formation and upper Vandalia Till Member. In this model, the stream valleys were incised into a nearly continuous upland surface. Alternatively, the present position of the North Fork Embarras valley may be related to subglacial drainage of the glacier that deposited the Mulberry Grove and Vandalia Till Members. In this scenario, the proto-North Fork Embarras River valley was initially a primary conduit for proglacial and subglacial discharge; less diamicton is present in the valley not because of erosion, but because diamicton was never deposited there. Boulton and Hindmarsh (1987) postulated a similar model of subglacial deposition in the development of tunnel valleys under warm-based glaciers. When the Vandalia glacier melted, the valley of the North Fork

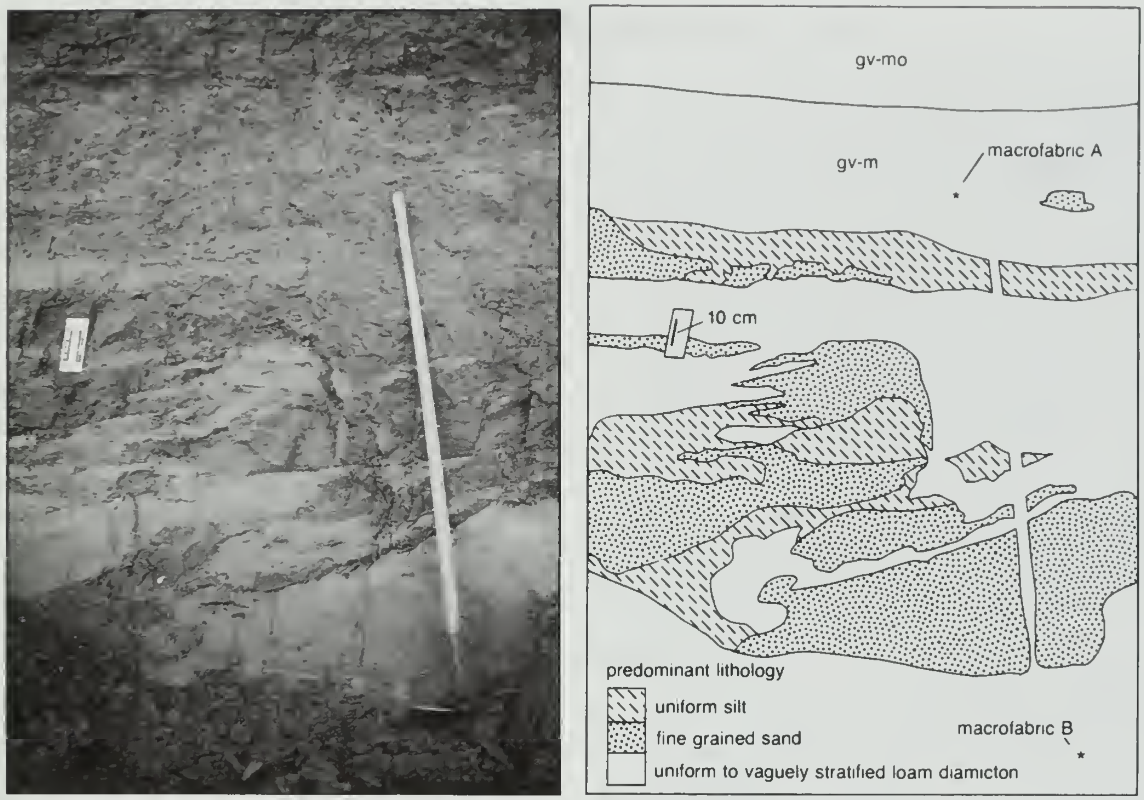

Figure 45 Sediment types of the mélange facies of the Vandalia Till Member, Glasford Formation, at CC–16. Area of photograph outlined in figure 44.

Embarras River may have been a route for meltwater from glacial activity north of the MAS during the upper Illinoian (Johnson et al. 1972, Lineback 1979a, b). Later, the valley was a route for drainage during the Sangamonian, Wisconsinan, and Holocene.

The age of most postglacial sediments in the North Fork Embarras River valley adjacent to the MAS appears to be younger than the upland postglacial sequences at the MAS. The upper silt loam facies of the Cahokia Alluvium in the valley of the North Fork Embarras River is Holocene, based on a radiocarbon age of ca. 8,300 yr B.P. from the base of the facies at H–1. The underlying sand and gravel facies of the Cahokia in this valley is largely composed of reworked late Wisconsinan outwash, or less likely, reworked late Illinoian outwash.

As was observed by Hajic (1990) in the Illinois and Mississippi River valley area, older alluvial sediment is more commonly preserved in tributary valleys than in the valleys of master streams. Patches of pre-Holocene sediment have been preserved in the alluvium of Bluegrass Creek, including a narrow terrace at CC–17 that contains a thin, wavy band of organic material and wood fragments that yielded an age of 23,720 ± 300 yr B.P. (ISGS-2113). From the Illinoian to the present, the lowest elevation Bluegrass Creek may have attained during periods of downcutting was about 557 feet, which is the elevation of the bedrock surface at M–120 near the mouth of Bluegrass Creek (fig. 2). At about 14,500 yr B.P., the mouth of Bluegrass Creek was no more than about 4 feet above its present level of about 575 feet, as indicated by the radiocarbon age (ISGS-2024) on wood from a depth of about 11 feet at M–120. This suggests net aggradation in the valley some time after 14,500 yr B.P., followed by incision to present stream levels during an unknown period.

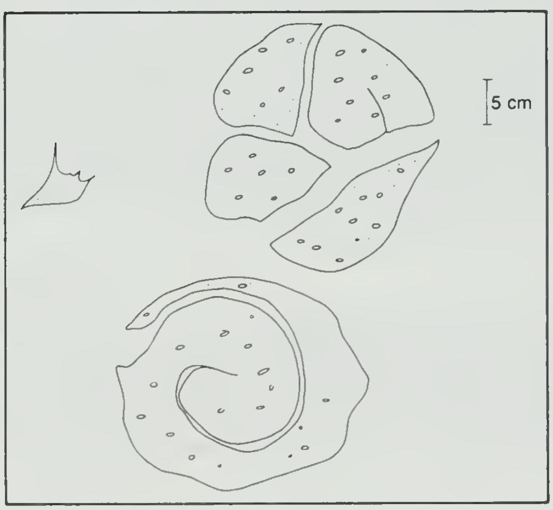

Figure 46 Sand and gravel bodies (stippled) in loam diamicton of the mélange facies are suggestive of soft sediment deformation under hydrostatic loading.

SUMMARY AND CONCLUSIONS

Quaternary deposits beneath the MAS fill two buried bedrock valleys (the Martinsville and North Fork Embarras bedrock valleys) above sandstone, siltstone, and shale of the Pennsylvanian Bond and Modesto Formations. The Martinsville bedrock valley had not been mapped prior to the MAS investigations. Pre-Illinoian deposits were not encountered at the MAS, but they are found 3 miles east of the MAS. The thicknesses of each primary Illinoian lithostratigraphic unit, including the Petersburg Silt, and the Smithboro Till, Mulberry Grove, and Vandalia Till Members of the Glasford Formation, are the greatest known in Illinois. Glacial drift varies in thickness from about 70 feet to more than 200 feet at the MAS, but it is absent in the valley of Bluegrass Creek just north of the site.

The base of the Quaternary succession at the MAS is the Yarmouthian Lierle Clay, composed of pedogenically altered sediment no more than 2 feet thick. This unit is overlain by the early Illinoian Martinsville sand, which was deposited during cool climate, and by as much as 50 feet of Petersburg Silt, interpreted as slackwater lacustrine sediment.

Silt loam and loam till of the Smithboro Member of the Glasford Formation, as much as 97 feet thick, overlies the Petersburg. The Smithboro is interpreted to have been deposited as subglacial till, initially by deformational processes and lodgement, and later by primarily lodgement or a deforming bed.

The overlying Mulberry Grove Member has three facies composed of diamicton, silt, and sand and gravel, primarily the latter. The Mulberry Grove Member was deposited under two contrasting environments. In subaerial proglacial environments, pedogenically altered fossiliferous silt was deposited, whereas in subglacial and ice marginal environments, sand and gravel and loam diamicton were deposited.

The Vandalia Till Member of the Glasford Formation has two facies, a lower uniform diamicton and a mélange facies. The uniform diamicton facies, as much as 129 feet thick, is composed of loam diamicton deposited subglacially by lodgement or by pervasive shear in a deforming bed. Subglacial channels filled with poorly sorted sand and gravel as much as 18.5 feet thick also occur in the uniform diamicton facies; however, the length, continuity, and width of the channels are unknown. The mélange facies, as much as 34 feet thick, typically overlies the uniform diamicton facies. The mélange consists chiefly of loam diamicton, with numerous discontinuities, inclusions and lenses of sand, and few inclusions of silt. The mélange facies was deposited in subglacial and ice marginal environments.

The Glasford Formation is overlain discontinuously by sand and gravel of the Pearl Formation, which is as much as 13 feet thick. The overlying Berry Clay Member is composed of leached loam and clay loam diamicton no more than 12 feet thick. The Pearl and Berry, as well as the upper mélange facies of the Vandalia, are leached and pedogenically modified by the Sangamon Soil. The Berry Clay Member is overlain by Wisconsinan loess as thick as 7 feet, including a lower zone of pedogenically mixed loess and weathered sediment composed of loam (Roxana Silt) and silt loam (Peoria Loess). Both units are pedogenically modified—the Roxana by the Farmdale Soil and the Peoria by the modern soil.

Streams and terraces along the North Fork Embarras River, Bluegrass Creek, Kettering Branch, and smaller valleys are underlain by Cahokia Alluvium. The Cahokia, as much as 35 feet thick, is composed of coarse granular sediment, well sorted medium sand, loam, and silt loam. Radiocarbon ages of 23,720 ± 300 yr B.P. (ISGS-2113), 14,490 ± 140 yr B.P. (ISGS-2024), 8,370 ± 300 yr B.P. (ISGS-2176), and 320 ± 70 yr B.P. (ISGS-2073) from wood within the Cahokia indicate an age that ranges from late Wisconsinan to Holocene. The presence of late Wisconsinan sand and gravel outwash (Henry Formation) cannot be confirmed in the valley of the North Fork Embarras River because neither the Roxana Silt, Berry Clay Member, nor Sangamon Soil is preserved in the valley.

Development of the drainage network on and immediately adjacent to the MAS probably began in the Illinoian during and after deposition of the Pearl Formation and the mélange facies of the Vandalia Till Member. Much of the relief across the North Fork Embarras River valley may have developed earlier during the time the Mulberry Grove Member and the Vandalia Till Member were deposited.

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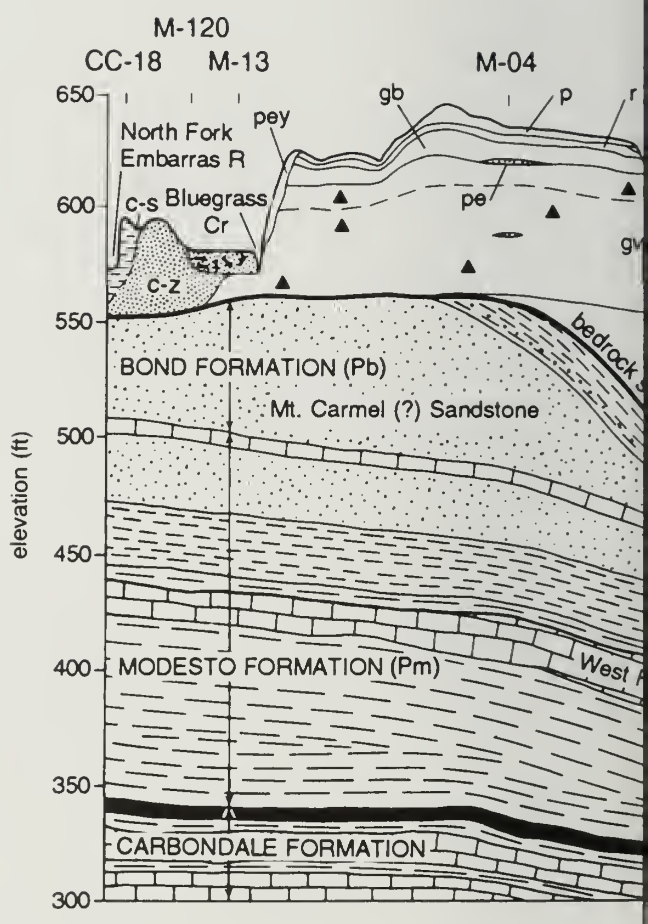
Appendix Meen values of particle-size determinations, semiquentitetive minerelogical analyses, end selected physical characteristics.

Unit	Particle size distribution				Coefficient of uniformity, Cu	Moisture content, %	Atterberg limits		
	Totel gravel, %	<2 mm, %					Liquid limit, %	Plestic limit, %	Plasticity index
		Sand	Silt	Cley					
Cehokie Alluvium (c)									
silt loam facies	0.6±1.1	16.7±13.1	53.1±13.2	30.1±11.9	24.6±19.2	23.8±8.5	34.0±9.5	18.8±3.6	17.1±8.4
(c-sl)	29(0-5)	29(2-53)	29(32-82)	29(7-59)	16(4.0-68.0)	16(14.8-51.5)	15(18-51)	15(14-26)	15(0-37)
sand and gravel	12.4±21.5	87.1±9.0	7.9±6.0	5.0±3.5	25.0±41.1	19.2±4.8	—	—	—
facies (c-z)	27(0-84)	27(64-97)	27(1-23)	27(2-16)	27(1.8-207.5)	25(8.5-29.1)			
Peoria Loess (p)	0.5±0.8	10.2±4.1	55.5±6.1	34.2±7.6	7.9±6.3	24.9±3.8	40.8±9.7	17.9±2.3	22.9±11.0
	37(0-3)	37(4-21)	37(44-69)	37(20-49)	32(0.6-18.5)	34(14-32)	18(28-60)	18(14-22)	18(7-44)
Roxana Silt, sandy-silt	1.2±1.4	25.2±6.5	40.8±4.8	33.8±5.5	15.5±11.8	20.5±3.7	33.8±8.1	13.6±1.7	25.2±8.1
fecies (r)	31(0-6)	31(6-38)	31(27-48)	31(20-46)	26(1.0-54.8)	27(8.8-28.7)	20(25-54)	20(11-18)	29(8-37)
Peerl Formetion (pe)	3.0±4.1	74.5±21.9	11.7±10.7	13.7±13.6	83.7±69.2	18.4±6.9	—	—	—
	12(0-15)	12(14-95)	12(3-37)	12(0-54)	8(2.6-255.0)	8(4.8-27.0)			
Berry Cley Member (peb)	3.7±2.8	37.0±9.5	30.1±7.4	32.7±6.4	44.9±48.5	20.1±3.4	35.2±6.3	12.3±1.6	22.9±6.0
end (gb)	75(0-16)	75(14-64)	75(15-47)	75(13-47)	68(1.5-185.0)	70(14.0-40.9)	46(21-48)	46(8-17)	46(6-35)
Glasford Formation									
Vandalia Till Member									
mélange facies									
weethered diemicton	5.5±3.2	44.5±4.4	28.7±6.2	26.6±3.8	134.1±6.4	11.9±1.7	—	—	—
(gv-mx)	6(3-11)	6(39-52)	6(22-38)	6(22-31)	3(125.2-139.6)	3(9.7-13.9)			
oxidized diemicton	5.8±4.3	45.6±5.0	30.7±3.5	23.6±4.2	71.1±66.1	11.8±4.6	21.5±3.1	11.8±1.2	9.6±3.0
(gv-mo)	43(1-28)	68(32-63)	68(22-39)	68(11-31)	42(1.5-312.3)	42(6.1-25.0)	24(15-28)	24(10-15)	24(3-15)
unoxidized diemicton	8.0±5.2	44.7±7.8	33.3±7.7	21.9±5.4	100.2±56.8	8.8±2.2	20.6±3.7	11.0±0.9	9.6±3.0
(gv-m)	93(1-33)	93(14-65)	93(19-68)	93(8-40)	93(4.5-298.6)	95(4.1-19.4)	80(14-41)	80(8-14)	80(3-28)
unoxidized sand and	5.9±5.3	88.3±6.0	7.8±4.8	3.8±1.6	10.3±12.0	16.7±4.1	—	—	—
gravel (gv-mz)	13(0-19)	13(77-96)	13(2-17)	13(1-6)	13(2.5-38.4)	11(10.0-25.9)			
uniform diamicton	8.4±4.8	42.4±4.7	35.1±4.8	22.4±3.4	86.6±62.8	9.9±1.6	21.9±2.2	11.8±0.9	10.1±2.2
facies (gv-u)	513(0-41)	522(14-71)	522(19-76)	522(3-38)	482(1.5-903.6)	479(4.7-21.3)	392(17-44)	392(8-18)	392(1-31)
total diamicton,	8.3±4.9	42.7±5.4	34.8±5.4	22.3±3.8	105.7±53.9	9.7±1.8	21.7±2.6	11.6±1.0	10.0±2.5
Vandafia Till Member	606(0-41)	615(14-71)	615(19-76)	615(8-40)	575(1.5-903.6)	574(4.1-21.3)	472(14-44)	472(8-18)	472(1-31)
unoxidized sand and	9.2±9.7	79.8±13.8	14.1±10.9	6.1±3.9	—	—	—	—	—
gravel facies (gv-z)	25(0-38)	26(56-96)	26(2-35)	26(1-13)					
Mulberry Grove Member									
sand and gravel	19.7±19.3	84.2±12.7	11.2±9.9	4.5±3.2	23.7±33.8	14.8±5.3	—	—	—
facies (gm-z)	69(0-77)	69(48-97)	69(1-41)	69(1-17)	63(2.0-176.5)	60(6.0-36.4)			
diamicton facies	11.6±6.8	42.3±7.0	37.7±5.8	19.8±4.1	97.8±50.0	11.2±2.9	20.4±1.8	12.0±0.7	8.4±1.8
(gm-d)	35(3-30)	35(31-62)	35(24-47)	35(8-27)	31(10.7-229.4)	29(5.2-19.5)	25(16-25)	25(11-13)	25(3-12)
silty loem facies	2.1±2.0	17.3±9.3	63.3±13.1	19.2±7.1	17.7±6.1	17.3±5.4	28.0±7.8	18.4±5.7	9.6±6.9
(gm-s)	12(0-8)	12(5-38)	12(38-78)	12(10-34)	12(4.5-25.1)	12(11.0-32.8)	9(21-46)	9(12-32)	9(0-20)
Smithboro Till Member									
loam diamicton	6.7±4.2	31.1±6.2	43.8±6.8	25.0±6.3	46.6±26.8	13.1±2.2	25.8±3.3	13.4±1.4	12.4±3.5
facies (gs)	134(0-24)	138(26-70)	138(17-56)	138(8-45)	111(11.4-209.7)	124(9.0-23.2)	107(18-40)	107(11-22)	107(1-28)
silt loam diamicton	3.6±3.0	18.4±4.5	56.7±8.0	24.7±5.7	24.7±6.2	17.3±2.9	28.4±3.7	15.6±2.1	12.8±4.2
facies (gs-s)	230(0-17)	233(2-25)	233(26-83)	233(10-52)	209(3.0-45.6)	222(10.1-31.8)	207(21-61)	207(11-27)	207(0-44)
total diamicton,	4.7±3.8	23.1±8.0	51.9±9.8	24.8±5.9	32.2±19.5	15.8±3.3	27.5±3.8	14.9±2.2	12.6±4.0
Smithboro,Till Member	364(0-24)	371(2-70)	371(17-83)	371(8-52)	320(0-209.7)	346(9-32)	314(18-61)	314(11-27)	314(0-44)
sand end gravel	23.3±27.7	76.1±11.5	15.7±7.0	8.1±5.1	—	12.5±5.8	—	—	—
facies (gs-z)	6(2-77)	8(61-93)	8(4-25)	8(2-17)		6(4.4-19.2)			
Petersburg Silt (ps)	1.3±3.4	11.2±16.1	66.8±14.9	21.9±9.9	—	22.1±4.4	28.9±4.6	18.9±2.9	10.0±5.2
	62(0-16)	62(0-94)	62(3-90)	62(3-47)		57(9.4-32.7)	47(21-45)	47(14-25)	47(0-23)
Martinsville sand									
sand end gravel	18.8±22.7	79.8±10.8	13.4±7.8	7.1±6.5	36.9±44.5	7.4±7.1	—	—	—
facies (ms-z)	51(0-90)	51(51-95)	51(0-36)	51(0-38)	45(2.5-156.8)	49(6.9-42.5)			
silty clay facies	0.6±0.7	22.9±16.5	42.1±18.6	34.6±17.8	6.4±8.4	19.1±2.7	46.0±3.3	15.3±1.9	30.6±1.9
(ms-s)	16(0-2)	16(2-52)	16(14-77)	16(13-76)	15(2.4-36.9)	15(15-23)	3(42-50)	3(14-18)	3(28-32)
diemicton facies	10.2±10.3	36.7±13.7	38.5±9.3	23.6±10.7	53.5±45.9	17.6±2.8	27.1±4.8	15.1±3.3	12.0±4.2
(ms-d)	16(0-31)	16(6-59)	16(23-55)	16(5-51)	12(3.1-149.0)	12(13.4-23.1)	8(22-38)	8(12-23)	8(7-22)
Banner Formation									
Lierle Clay	4.01±9.5	28.7±11.8	40.2±13.6	31.1±8.0	—	—	—	—	—
Member (bl)	12(0-35)	12(7-54)	12(26-70)	12(17-48)					
Casey till member	—	30.5±5.1	39.8±5.3	29.9±4.2	—	—	—	—	—
oxidized (bc-o)		16(23-44)	16(31-52)	16(21-37)					
Casey till member	—	37.6±6.9	38.2±4.4	24.2±4.8	—	—	—	—	—
unoxidized (bc)		12(25-46)	12(32-48)	12(19-36)					

Unit	Expandable clay minerals, %	Illite, %	Chlorite & kaolinite, %	Calcite, cps	Dolomite cps	Vermiculite index	Diffraction intensity ratio	Heterogeneous swelling index	Total counts per second
	Mineralogy of the <2 μm fraction								
Cahokia Alluvium (c)									
silt loam facies (c-sl)	49.8±16.6 30(10-79)	34.2±12.3 30(14-59)	18.6±6.1 30(0-35)	1.6±6.6 30(0-35)	1.8±7.6 30(0-40)	29.9±9.6 30(11-46)	1.4±0.3 30(0.7-2.0)	9.4±6.8 30(1-24)	2069±1215 30(641-5200)
sand and gravel facies (c-z)	—	—	—	—	—	—	—	—	—
Peoria Loess (p)	53.2±14.6 28(27-82)	27.7±9.2 28(11-44)	19.0±7.1 28(7-36)	-0- 28(0-0)	-0- 27(20-55)	38.4±8.2 27(20-55)	1.0±0.4 28(0.7-2.0)	7.2±4.6 27(1-19)	2173±1024 28(610-3980)
Roxana Silt, sandy-silt facies (r)	67.5±12.0 24(37-87)	18.6±8.5 24-(6-44)	13.7±4.3 24(7-23)	-0- 24(0-0)	-0- 24(0-0)	46.9±7.6 23(32-59)	0.9±0.3 24(0.6-1.6)	8.0±4.6 24(3-26)	3217±1513 24(750-6450)
Pearl Formation (pe)	37.3±19.3 6(13-59)	47.6±16.2 6(28-70)	15.0±5.4 6(7-23)	5.0±11.2 6(0-31)	10.0±22.4 6(0-60)	—	2.1±0.8 6(1.3-38)	6.3±6.9 6(0-18)	2390±822 6(1410-3680)
Berry Clay Member (peb) and (gb)	59.4±18.0 63(11-89)	26.7±15.5 63(6-71)	13.6±4.7 63(4-23)	0.5±4.1 63(0-33)	0.4±3.5 63(0-28)	41.0±13.0 63(4-69)	1.3±0.6 63(0.4-3.3)	8.1±6.6 63(0-28)	3235±1761 63(1050-7890)
Glasford Formation									
Vandalia Till Member									
mélange facies									
weathered diamicton (gv-mx)	29.1±7.1 9(15-38)	59.1±8.2 9(49-72)	11.7±2.8 8(8-17)	9.0±18.0 5(0-45)	7.0±14.0 5(0-35)	20.0±6.2 8(8-25)	3.6±1.3 9(1.9-6.0)	4.6±3.3 5(0-10)	2499±856 5(1790-4126)
oxidized diamicton (gv-mo)	18.2±7.0 86(5-60)	66.1±6.5 86(40-80)	15.6±3.8 86(7.24)	42.2±29.1 84(0-207)	36.4±27.3 84(0.227)	11.4±6.3 56(2-34)	3.0±1.0 86(1.7-7.3)	1.4±1.7 52(0-6)	2030±546 54(1070-3500)
unoxidized diamicton (gv-m)	12.5±6.2 80(7-44)	59.3±6.6 80(26-69)	28.1±3.4 80(15-35)	57.4±18.0 80(0-100)	39.9±10.8 (0-72)	5.7±6.6 80(-3-31)	1.4±0.3 80(0.5-3.1)	0.2-0.8 81(0-6)	2461±495 80(1620-3860)
unoxidized sand and gravel (gv-mz)	—	—	—	—	—	—	—	—	—
uniform diamicton facies (gv-u)	12.4±4.1 401(3-40)	57.5±4.3 401(42-74)	29.9±3.3 401(12-39)	49.2±14.8 401(10-98)	34.7±11.0 401(0-75)	6.4±4.7 380(-6-40)	1.3±0.3 401(0.8-3.9)	0.1±0.6 382(0-10)	2493±523 380(890-5090)
total diamicton, Vandalia Till Member	12.4±4.5 481(3-44)	57.8±4.8 481(26-74)	29.6-3.4 481(12-39)	50.6±15.7 481(0-100)	35.6±11.2 481(0-75)	6.3±5.0 460(-6-40)	1.3±0.3 481(0.5-3.9)	0.1±0.7 463(0-10)	2488±518 460(890-5090)
unoxidized sand and gravel (gv-z)	—	—	—	—	—	—	—	—	—
Mulberry Grove Member sand and gravel facies (gm-z)	—	—	—	—	—	—	—	—	—
diamicton facies (gm-d)	12.1±6.0 49(3-30)	60.2±6.8 49(45-76)	27.6±3.7 49(17-36)	42.9±16.1 49(0-115)	35.4±13.1 49(0-97)	3.8±8.1 49(-16-22)	1.5±0.4 49(1.0-2.9)	0.2±0.8 49(0-4)	2615±642 49(1250-4020)
silty loam facies (gm-s)	22.9±11.1 20(9-53)	49.8±10.8 20(22-64)	27.2±2.9 20(24-33)	32.9±22.3 20(0-95)	22.8±17.2 20(0-57)	14.1±10.2 20(-7-32)	1.2±0.3 20(0.5-1.7)	1.7±2.3 20(0-9)	2268±809 20(840-3880)
Smithboro Till Member									
loam diamicton facies (gs)	22.6±9.1 126(5-48)	48.8±5.9 126(29-61)	28.4±5.5 126(20-45)	34.3±13.3 126(0-61)	25.2±10.3 126(0-45)	16.6±7.3 125(0-33)	1.2±0.2 125(0.5-1.8)	1.0±1.5 122(0-9)	2459±576 122(1150-4976)
silt loam diamicton facies (gs-s)	29.2±9.3 150(6-64)	42.5±7.1 150(17-59)	28.2±6.5 150(16-51)	24.5±13.6 15(0-50)	21.2±12.2 150(0-50)	23.1±6.3 146(9-45)	1.1±0.3 150(0.4-2.0)	1.6±2.0 146(0-8)	2294±669 148(880-4760)
total diamicton Smithboro Till Member	26.2±9.7 276(5-64)	45.4±7.3 276(17-61)	28.3±6.1 276(16-51)	29.0±14.3 276(0-61)	23.0±11.6 276(0-50)	20.2±7.5 268(0-45)	1.1±0.3 268(0.4-2.0)	1.3±1.8 275(0-9)	2368±634 270(880-4970)
sand and gravel facies (gs-z)	—	—	—	—	—	—	—	—	—
Petersburg Silt (ps)	18.8±7.1 37(12-51)	51.7±6.4 37(31-62)	29.3±5.0 37(18-46)	21.6±14.6 37(0-48)	16.2±12.5 37(0-37)	16.0±6.4 38(7-37)	1.2±0.2 37(0.6-1.7)	0.8±1.9 37(0-10)	1840±531 37(900-2900)
Martinsville sand sand and gravel facies (ms-z)	—	—	—	—	—	—	—	—	—
silty clay facies (ms-s)	22.3±13.0 20(2-45)	42.6±18.3 20(16-85)	35.0±10.1 20(9-57)	7.6±13.5 20(0-40)	4.3±10.5 20(0-37)	19.4±12.2 20(-8-36)	1.1±1.2 20(0.2-6.0)	0.6±1.6 20(0-7)	2220±796 20(1340-4190)
diamicton facies (ms-d)	22.9±7.3 16(13-34)	40.6±8.0 16(25-51)	36.3±6.7 16(22-46)	18.9±20.1 16(0-40)	10.4±11.8 16(0-80)	19.5±8.2 16(3-33)	0.8±0.3 16(0.4-1.4)	2.3±3.6 16(0-12)	1623±599 16(830-2630)
Banner Formation									
Lierle Clay Member (bl)	43.0±13.0 14(13-60)	31.9±9.0 14(25-59)	25.1±6.4 14(15-42)	0 14(0)	0 14(0)	32.6±10.4 14(8-48)	0.9±0.2 14(0.6-1.4)	5.1±3.0 14(0-9)	2574±711 14(1190-4040)
Casey till member oxidized (bc-o)	21.8±7.0 24(10-40)	60.0±6.3 24(45-70)	18.2±5.2 24(10-30)	29.4±15.5 21(4-63)	13.6±7.5 22(0-30)	24.3±7.3 8(15-32)	2.4±0.8 24(1.2-4.3)	1.3±1.1 6(0-3)	1583±240 8(1170-1790)
Casey till member unoxidized (bc)	8.3±4.0 18(4-20)	62.8±4.7 18(56-70)	28.9±3.8 18(22-36)	30.4±13.2 18(13-70)	13.4±5.9 18(7-34)	13.7±2.7 9(9-17)	1.5±0.3 18(1.1-1.9)	0 9(0-0)	1629±538 9(1050-2730)



M-120
CC-18
M-13
M-04
650
600
550
500
450
400
350
300
elevation (ft)
pey
gb
p
North Fork
Embarras R
c-s
Bluegrass
Cr
pe
c-z
BOND FORMATION (Pb)
Mt. Carmel (?) Sandstone
MODESTO FORMATION (Pm)
CARBONDALE FORMATION